MANUAL OF

Hand Injuries

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by

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Foreword by MICHAEL L MASON, M D

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Foreword

THE PAST 25 years have seen surgery of the hand develop from a concern largely of the general surgeon in a struggle to combat infection to an extensive and varied field With Kanavel's first publications in 1906–07 and the publication of his text on *Infections of the Hand* in 1912, a door was opened to a whole new field of surgery. This landmark of surgery, though not the first book dealing with the hand, was the first experimental and clinical treatise to appear and undoubtedly the most important Not until hand infections were understood and methods for combating them pointed out could serious and fruitful consideration be given to the hazardous repair of open wounds, the complicated reconstructive procedures necessary to rehabilitate disabled hands and the various elective procedures in such conditions as Dupuytren's contracture and congenital deformities Between World Wars I and II a few men here and there became interested in surgery of the hand and there gradually developed a few centers where surgery of the hand was pursued as a special though not exclusive field These earlier clinics owed much of their success in the management of surgical conditions of the hand to the groundwork laid down by Kanavel and to tenets established by Halsted One principle adopted especially by the plastic surgeons, namely a great respect for the integrity of the delicate tissues with which they were called upon to deal, has influenced the whole outlook on general surgical technic This "atraumatic technic," so named by Bunnell, must govern all phases of surgery of the hand, whether one is draining an infection, repairing an acute injury, dissecting out the palmar fascia in a case of Dupuytren's contracture or grafting a tendon to restore motion in a finger The surgeon must have not only an aseptic conscience but also

an atraumatic one, he must be just as sensitive to lapses in careful, gentle, tissue-sparing technic as he is to breaks in asepsis.

The rapid growth in interest and the expansion in development of suitable technics in hand surgery are due to the greatly augmented appreciation of the functional value of the hand both economically and socially Coupled with this is the realization that surgery of the hand demands certain special training which is seldom acquired in school or resident-training programs Many of the larger hospitals and clinics and many communities funnel "hand cases," particularly the difficult ones, to certain individuals with special interest in them who have become proficient in their care Success in the surgical management of hand conditions depends upon a mastery of the technics, a sound knowledge of the anatomy and physiology of the hand and the ability and patience to work carefully and painstakingly on even the smallest procedures Final reconstructive procedures on the more severe hand wounds may demand the skills of plastic and orthopedic surgeons However, the immediate emergency—the care of the acute injury—is often of more importance, since primary care skillfully carried out frequently obviates the need for late reconstructive operations Hence it is necessary that every surgeon understand the general principles underlying care of wounds of the hand so that he can undertake initial proper care when the occasion presents itself

This volume by Dr Nichols deals essentially with the acute phases of surgery of the hand, that is, with the care of injuries and infections Anatomy as the basis of all well planned surgery is given its due place as the leading chapter, followed by the general principles of technic underlying all procedures on the hand The discussion of management of wounds and infections is based upon the author's personal experience well tempered with wide reading in the field The inclusion of methods of skin grafting and the formation of pedunculated flaps is particularly appropriate, for these are part of the armamentarium of the surgeon dealing with acute surgery of the hand Dr Nichols' book will be of great use in the care of acute injuries since, without being dogmatic, he presents those methods which he has found successful. Clearly illustrated with diagrams and drawings as well as with photographs of pertinent cases, the volume can well serve as a reliable guide to this interesting and important field of surgery.

MICHAEL L. MASON

Preface to the Second Edition

SINCE the acceptance of the *first* edition of this book, new types of injuries have appeared and new methods of treatment have been tried out In dealing with some of the more serious injuries, attempts have been made to salvage a partially useful member instead of amputating it New material has been incorporated in the old chapters, and a short new chapter on crush injuries has been added Some paragraphs no longer important have been deleted The reader is again cautioned against attempting complicated procedures unless he has had special surgical training and experience

I have tried to make the material "come alive." All text is based on actual cases, and all drawings are from photographs of cases, line drawings have been used for clarity and simplicity

Again I express my appreciation to my colleagues and to Dr Mason and Miss Ashworth

H M.N

PREFACE TO FIRST EDITION

INJURIES of the hand are among the most common conditions brought to the attention of the general physician and surgeon, whether in rural or industrial areas Because the risk of permanent disability is so great in

hand injuries, the importance of proper management cannot be too strongly emphasized As the late Dr. Homer D Dudley so aptly stated, "Success in treating a severe hand injury requires more skill and exacting judgment than an elective abdominal operation."

This manual has been prepared in order to make available in one concise volume the principles of treatment of the multiform injuries and infections involving the hand It is written essentially for medical students, interns, residents and practicing surgeons, and the procedures described are the simplest compatible with good functional results. In each section, appropriate illustrations are used to show, by diagram, the technic applied and, by photographs, the results obtained in personal cases When multiple technics are presented, emphasis is placed on the fundamental surgical principles involved Knowledge of these principles should enable the surgeon to select the best of the innumerable new technics and drugs that are constantly appearing Drug names, dosages and unproved and bizarre technical procedures have been purposely omitted

Two short chapters on reconstructive procedures are included to supplement the earlier, basic chapters in which references are made to secondary tendon repair, bone grafting, etc These chapters are not intended to be complete The reader is referred to texts in plastic surgery, hand surgery or orthopedic surgery in which a tremendous variety of reconstructive operations can be found An attempt by other than experienced surgeons to carry out any but the simplest of these is not recommended

In the preparation of this manual, reference has been made to the standard textbooks on anatomy, surgery and fractures as well as to the texts on surgery of the hand by Bunnell, Islen, Handfield-Jones and Cutler and to the numerous contributions to the literature by Koch and Mason. To my colleagues who have contributed clinical material and advice I wish to express my appreciation, especially to Drs. Wilmer C Smith, C E Carlson and A G Bettman For helpful suggestions and constructive criticism in various stages of the preparation of the manuscript I am deeply grateful to Dr Michael L Mason Appreciation is expressed to Clarice Ashworth for her meticulous work on the illustrations, to Beverly Felder for typing the manuscript and to Sylva Gibbons for editorial assistance

H M N

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An Atlas of Surgical Anatomy of the Hand

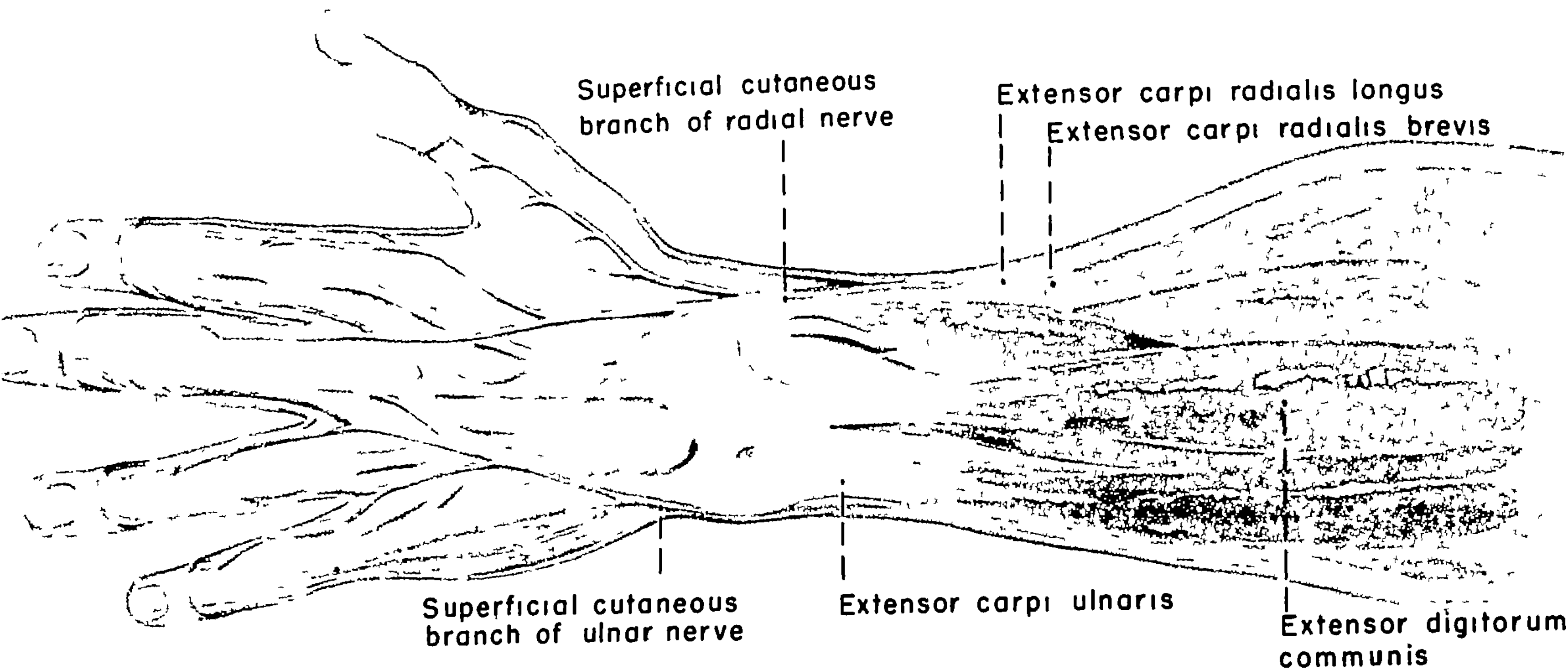


FIG 1—Dorsum of hand and forearm *Plate I,* skin removed, exposing deep fascia and cutaneous nerves

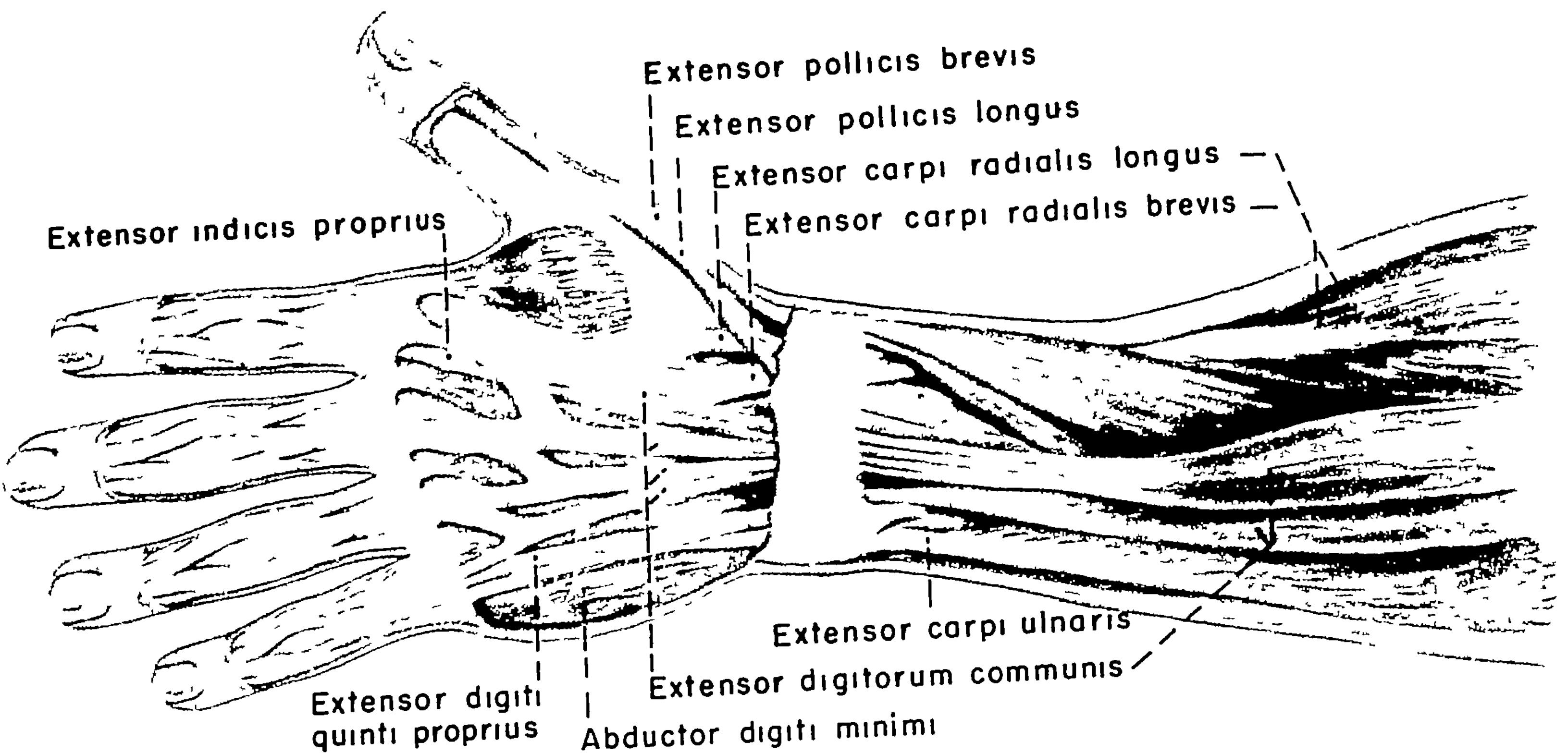


FIG. 1 *(cont.)*.—*Plate II*, deep fascia removed, exposing tendons and muscles.

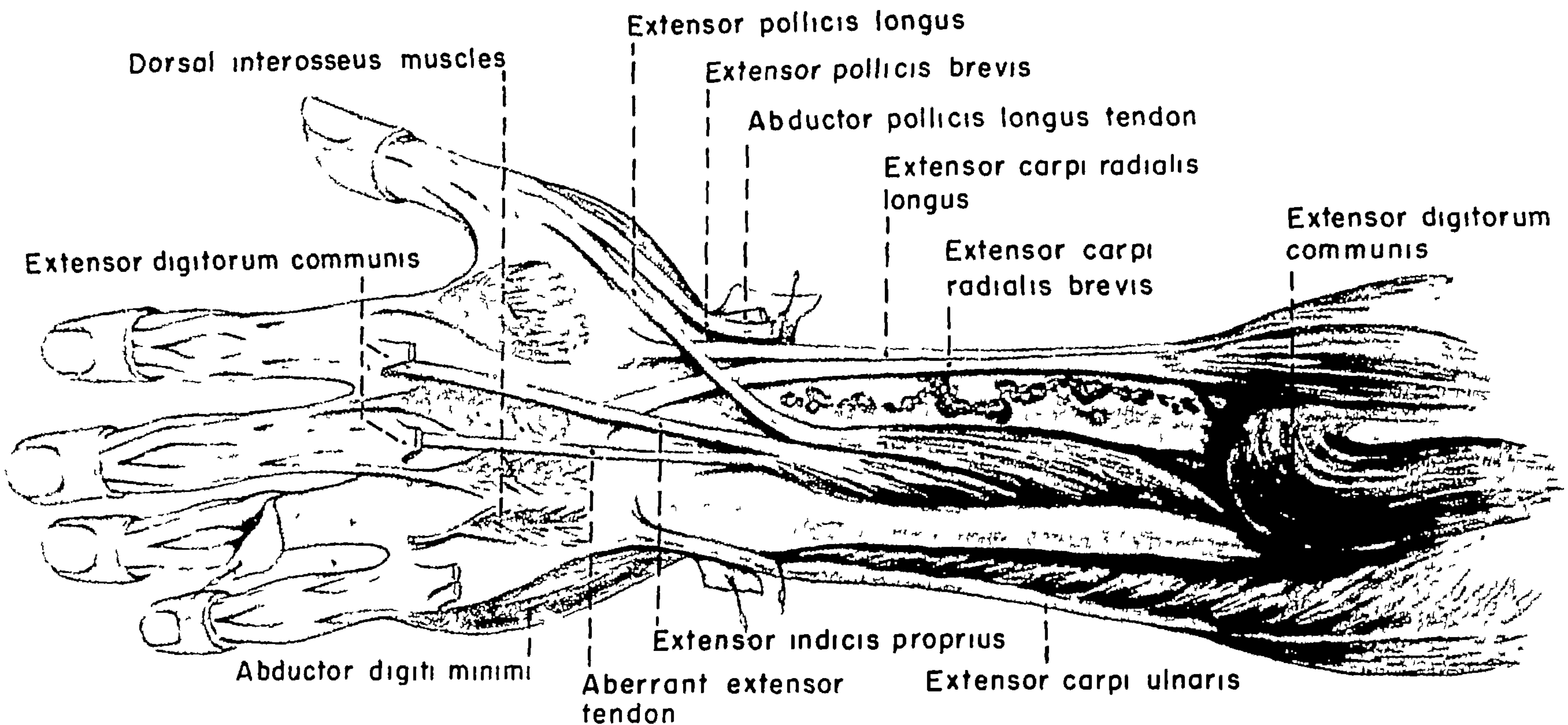


FIG. 1 *(cont)* —*Plate III,* superficial muscles and tendons removed, exposing deep muscles, radius and ulna.

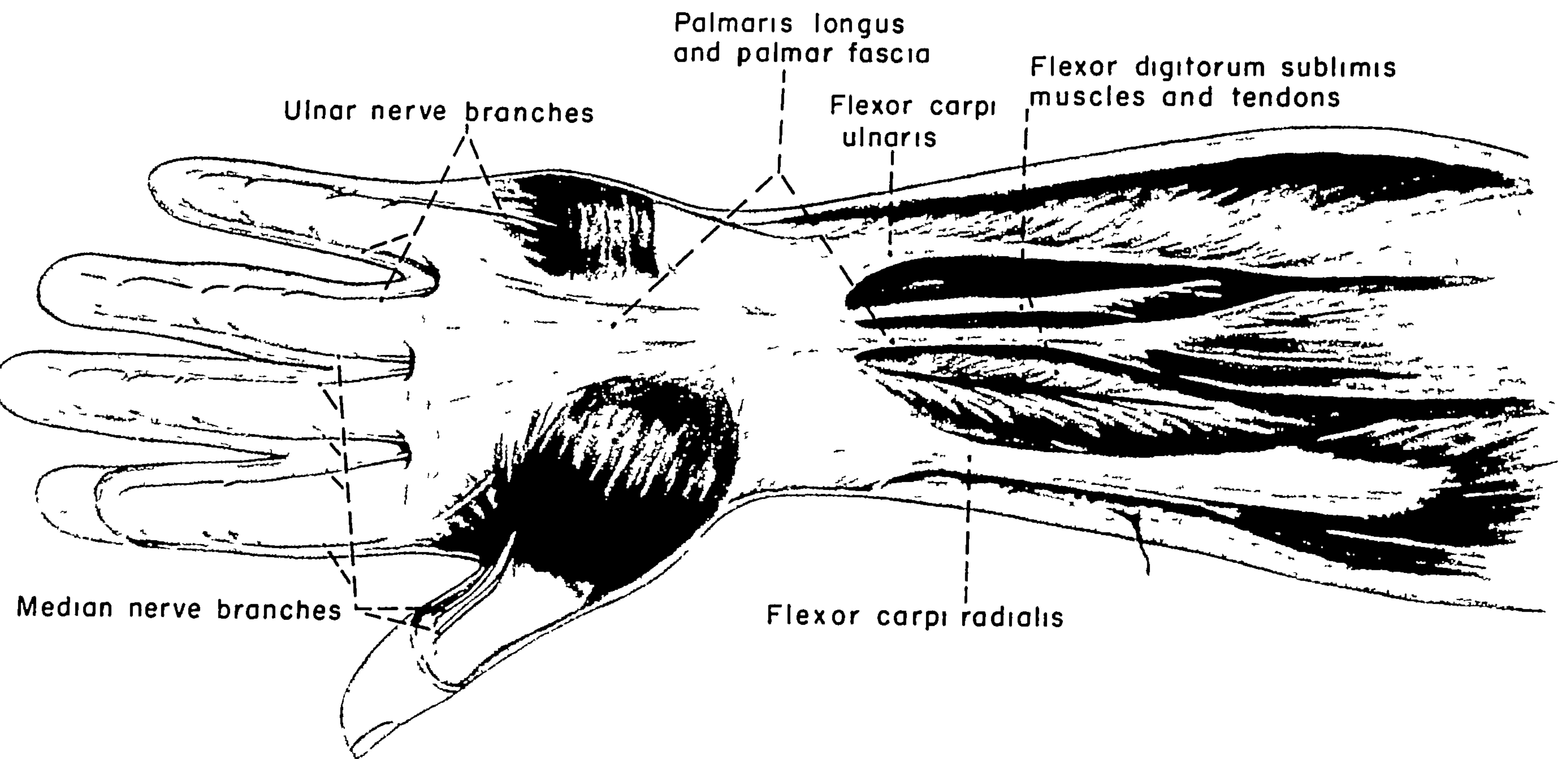


FIG. 2—Volar surface of hand and forearm *Plate I,* skin removed, exposing palmar fascia and digital nerves Superficial muscles and tendons show through thin fascia

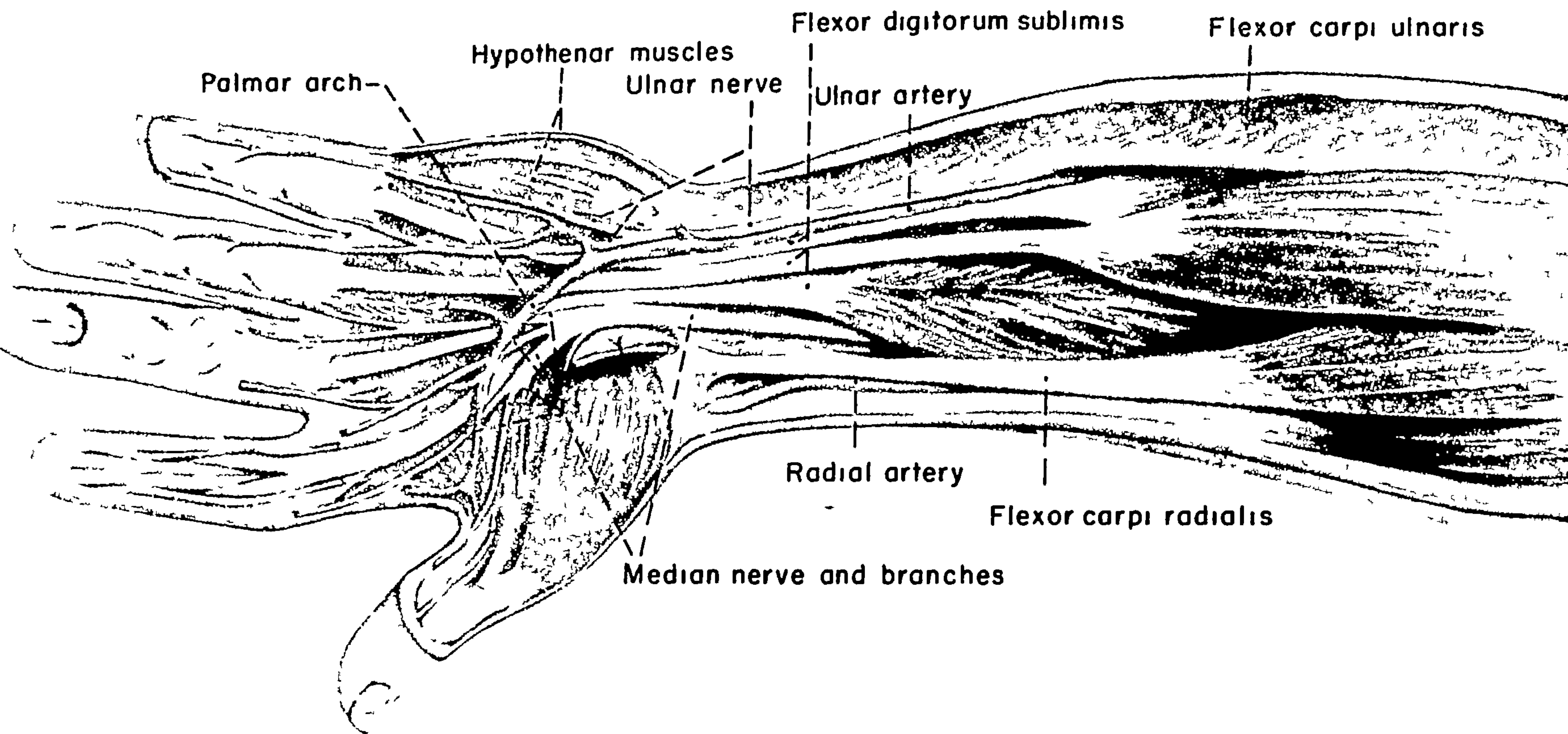


FIG 2 (*cont*)—*Plate II*, transverse carpal ligament cut and deep fascia of the forearm, palmaris longus and palmar fascia removed, exposing superficial tendons, ulnar nerve and median nerve

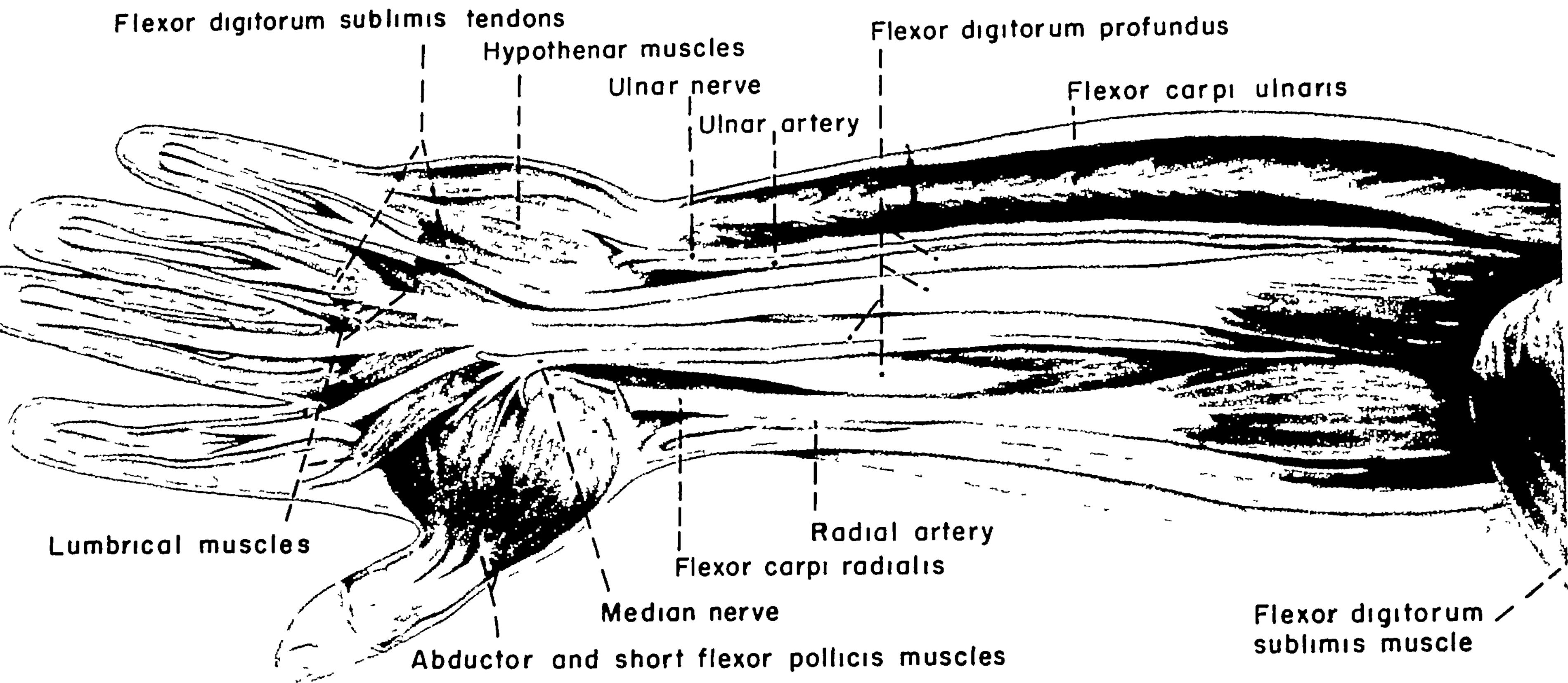


FIG. 2 *(cont.)* —*Plate III,* sublimis muscles and nerves and tendons removed from palm, exposing profundus muscles and tendons with lumbricales

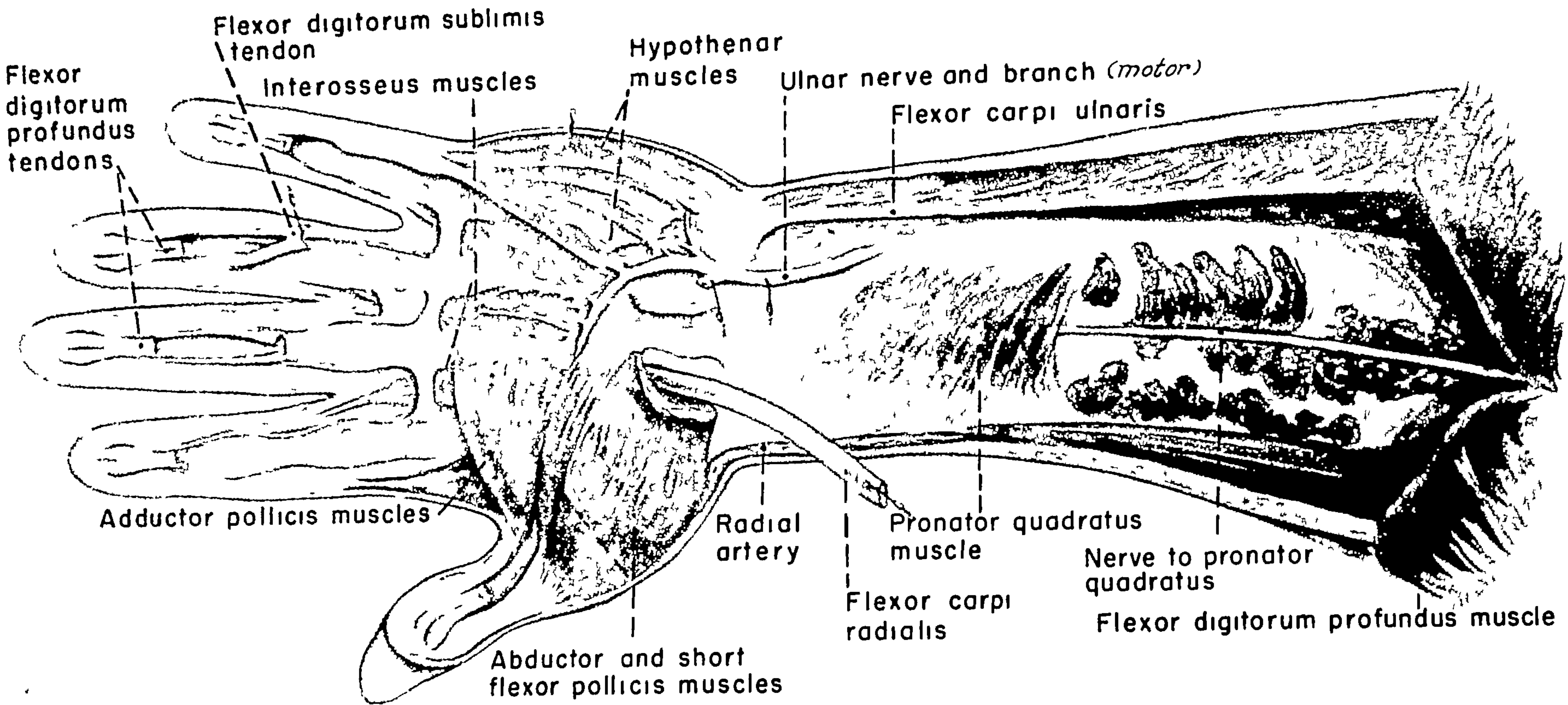


FIG. 2 *(cont)*—*Plate IV*, deep tendons removed, showing tendon sheaths, radius and ulna, pronator quadratus and deep branch of ulnar nerve supplying muscles in palm.

CHAPTER ONE

Anatomy

A CONCISE knowledge of the anatomy of the hand and forearm is essential to surgery of this region In this chapter emphasis is placed on the anatomic features which are important from the surgical point of view. Accompanying the text are plates drawn from dissections of a freshly amputated extremity, thus avoiding the distortions usually found in cadaver specimens

The dissections were carried out in layers In Figures 1 and 2, Plate I shows the deep fascia after the skin and superficial fascia have been removed In this layer the digital nerves and arteries on the front of the hand and the sensory branches of the ulnar and radial nerves on the dorsum of the hand are shown as they perforate the deep fascia and come to lie in the subcutaneous fat Some of these fat deposits are illustrated in the dissection of this layer The deep fascia was then removed Plate II for the dorsal and the volar surface shows the superficial layer of muscles in the forearm and the nerves, arteries and tendons in the palm The superficial muscles were then removed (Plate III), revealing the deep muscles in the forearm, the profundus group of tendons in the palm and the lumbrical muscles here Since the nerves and arteries lie superficial to the tendons in the palm, they are shown displaced or removed, but in the forearm where the nerves and vessels lie between the superficial and deep muscles they are left intact for this illustration The deep group of muscles was then removed, leaving the small muscles in the hand and the pronator quadratus in the forearm (Plate IV, Fig 2)

As the dissection progressed, each stage was photographed, the artist's drawing could thus be checked against the photographs for possible

errors in proportions Since most surgery is carried out with the hand in a flattened position, this position was adopted for the illustrations The text takes up the description of the layers of the skin and deep fascia, the muscles and tendons, arteries and veins, nerves and, finally, the bones and joints in this order

SKIN AND LANDMARKS

SKIN —The skin covering the hand is adaptively different from the skin on other parts of the body On the dorsum it is supplied with hair follicles, is rather more elastic than elsewhere and is held in place by a layer of loose areolar tissue There are small redundant areas over each joint which wrinkle up when the hand is extended and stretch flat when it is flexed Beneath the skin on the dorsum of the hand are numerous rather large veins A few small sensory nerves are present and only a little fat The only attachments to deeper structures on the dorsum are around the nail and along the sides of the fingers and palm Directly beneath the superficial fascia is the aponeurosis of the extensor mechanism

On the palm, the skin is thickened and hairless and shows the characteristic whorls and flexion creases The superficial fascia here contains numerous fatty elastic pads which give protection to the underlying structures This fascia is attached directly to the palmar fascia by many vertical fibers and at the flexion creases unites the skin directly to the deep fascia

The *creases* on the palm of the hand are opposite the joints Of the two principal transverse creases, the distal is used in movements of the ring and little fingers and the proximal in movements of the index and long fingers The crease at the base of the thumb is used in opposition of the thumb The transverse palmar creases are approximately opposite the metacarpophalangeal joints The proximal finger creases opposite the middle of the proximal phalanges anchor the distal palm and the finger webs to the deep structures

The *skin whorls* or rugae of the palmar skin are formed by ridges of epidermis dotted with sweat-gland openings These allow increased tactile sensation The center of the finger whorl is the most sensitive part

EMINENCES —In addition to the padding on the volar surface provided by the specialized subcutaneous fat, the small muscles of the thenar and hypothenar eminences give contour to the hand The thenar muscles form a cone about the metacarpal of the thumb, especially when the thumb is brought into opposition, even when the hand is flattened, they still make the base of the palm concave These muscles move the metacarpal and the proximal phalanx of the thumb The hypothenar muscles have a

somewhat similar function, but to a considerably lesser degree, in opposing the little finger and giving concavity to the palm

BONY LANDMARKS—The styloid processes of the radius and ulna are prominent under the skin on the sides of the wrist The wrist joint lies between them, with about two thirds of the carpal bones adjacent to the radius. The pisiform and tubercle of the navicular bone are fairly easily felt at the base of the hand just distal to the distal flexion crease of the wrist On the back of the hand the metacarpals may be felt throughout most of their length, the bases of the second and third metacarpals forming a slight prominence The navicular may be palpated in the wrist region between the long extensor tendons of the index finger and the thumb With the fingers flexed, the bony prominences of the knuckles are formed by the heads of the metacarpals

DEEP FASCIA

The deep fascia of the hand and forearm includes a number of special thickenings which have so often been described separately that one loses sight of the fact that they are all continuations of the structure that surrounds the muscles of the extremity The lacertus fibrosus at the elbow, the volar and dorsal carpal ligaments at the wrist, the palmar fascia and the digital tendon sheaths are all related to this structure The deep fascia of the forearm is continuous with the deep fascia of the arm At the elbow, in addition to the lacertus fibrosus, there are heavy thickenings which extend from the humeral condyles to the common tendons of origin of the flexor and extensor muscles of the forearm This fascia is attached to the posterior border of the ulna and thins out over the bellies of the muscles Above the wrist the fascia is traversed by the tendon of the palmaris longus and the ulnar artery and nerve

On the front of the wrist lies the *anterior annular ligament,* or *transverse carpal ligament,* which is attached laterally to the navicular and greater multangular bones and medially to the pisiform and hamate bones This forms the roof of the carpal canal It is divided into two compartments, one containing the flexor carpi radialis and the other, the larger, the flexors of the digits and the median nerve To the distal border of the transverse carpal ligament are attached the palmar fascia and the superficial short muscles of the thumb and little finger

The *palmar fascia* is that part of the deep fascia which occurs in the palm of the hand, extending roughly from the base of the palm to the webs of the fingers This structure is divided into a specialized, thickened, triangular central part which overlies the tendons, nerves and vessels in

the palm and the thinned-out lateral and medial portions which cover respectively the muscles of the thenar and hypothenar regions. It is the triangular central part which is of special surgical importance.

Proximally, the fibers of the triangle converge and are continuous with the palmaris longus and also densely attached to the transverse carpal ligament Distally, the fibers divide into four slips over the heads of the metacarpals, and each of these slips further splits into two processes which are inserted into the sides of the fibrous sheaths of the flexor tendons Between the metacarpal heads are openings for the passage of the digital nerves and vessels Just distal to the metacarpal heads are transverse bands which bind the fingers together at the level of the skin of the web In addition, there are heavy transverse fibers between each of the four principal slips which parallel the metacarpals. Superficially, various vertical fibers bind the palmar fascia densely to the overlying skin at each important flexion crease in the palm and at the proximal finger creases Deeply, vertical fibers bind the palmar fascia to the sides of the tendon sheaths, to the lateral portions overlying the thenar and hypothenar muscles and to the transverse metacarpal ligament. In the distal palm the arrangement of the fibers arching over the tendon sheaths is such that seven tunnel-like openings are provided through which pass alternately tendons, and nerves and vessels

The *digital sheaths* are exceedingly dense fibrous structures which support the flexor tendons and prevent them from bowing out from the phalanges when the fingers are flexed These are alternately thinned out over the joints to allow for flexion and thickened along the shafts of the phalanges where tension is greatest They are attached to the lateral borders of the phalanges The tendons here are enveloped in a synovial membrane which extends from the distal phalanges to the metacarpal necks There are not only synovial membranes for each tendon but, in addition, two large bursae which envelop the tendons in the palm and extend up above the wrist joint *

On the back of the hand the principal thickening of the deep fascia is the *dorsal carpal ligament.* This is a band of fibers about 1 in broad which binds the extensor tendons into the grooves on the dorsum of the radius and the styloid process of the ulna There are six compartments beneath the dorsal carpal ligament, formed by the attachment of separate bands extending to the bones beneath Each compartment contains a synovial membrane The most lateral of the compartments contains the abductor pollicis longus and the extensor brevis Next lie the long and

* Further description of the fascial spaces and bursae is given in Chapter 12

short radiocarpal extensors and next the extensor pollicis longus Centrally placed are the extensor digitorum communis and extensor indicis proprius, and toward the ulna the extensor digiti quinti proprius The extensor carpi ulnaris occupies the most ulnar position and frequently lies in a medial position on the side rather than the dorsum of the wrist The deep fascia on the dorsum of the hand is quite thin and gradually fades out over the dorsal aponeurosis of the extensor tendons on the fingers

MUSCLES OF THE FOREARM

In this description the muscles are grouped, as they are in most anatomy texts, into those on the front and those on the back of the forearm and, for each surface, into a superficial group and a deep group For simplicity's sake, the origin of the muscles is given as a general location based on the group of muscles, and their minute origins are omitted

FRONT OF THE FOREARM, SUPERFICIAL GROUP—The superficial muscles of the front of the forearm are the pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris and flexor digitorum sublimis

Origin—These muscles have a common tendinous origin from the medial epicondyle of the humerus, and from this region additional fascial fibers pass to the septa between the various muscles and to the antibrachial fascia The coronoid process of the ulna and the collateral ligament of the elbow are part of the general origin

Insertion—The pronator teres inserts into the middle of the shaft of the radius on its lateral surface The flexor carpi radialis inserts into the bases of the second and third metacarpal bones The palmaris longus inserts into the central part of the transverse carpal ligament and into the palmar aponeurosis The flexor carpi ulnaris inserts into the pisiform, thence a tendinous band passes to the fifth metacarpal base The four flexor digitorum sublimis tendons pass under the transverse carpal ligament through the palm of the hand and insert on the lateral border of the middle phalanges of the digits

FRONT OF THE FOREARM, DEEP GROUP—The deep group of the forearm muscles is composed of the flexor digitorum profundus, flexor pollicis longus and pronator quadratus

Origin and insertion—The flexor digitorum profundus arises from the upper two thirds of the anterior surface of the ulna and the flexor pollicis longus from the corresponding area on the radius Both of these muscles also have some origin from the interosseous membrane connecting the radius and ulna in this area These muscles have tendons which pass deep

the palm and the thinned-out lateral and medial portions which cover respectively the muscles of the thenar and hypothenar regions. It is the triangular central part which is of special surgical importance.

Proximally, the fibers of the triangle converge and are continuous with the palmaris longus and also densely attached to the transverse carpal ligament. Distally, the fibers divide into four slips over the heads of the metacarpals, and each of these slips further splits into two processes which are inserted into the sides of the fibrous sheaths of the flexor tendons Between the metacarpal heads are openings for the passage of the digital nerves and vessels Just distal to the metacarpal heads are transverse bands which bind the fingers together at the level of the skin of the web In addition, there are heavy transverse fibers between each of the four principal slips which parallel the metacarpals Superficially, various vertical fibers bind the palmar fascia densely to the overlying skin at each important flexion crease in the palm and at the proximal finger creases Deeply, vertical fibers bind the palmar fascia to the sides of the tendon sheaths, to the lateral portions overlying the thenar and hypothenar muscles and to the transverse metacarpal ligament. In the distal palm the arrangement of the fibers arching over the tendon sheaths is such that seven tunnel-like openings are provided through which pass alternately tendons, and nerves and vessels

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On the back of the hand the principal thickening of the deep fascia is the *dorsal carpal ligament* This is a band of fibers about 1 in broad which binds the extensor tendons into the grooves on the dorsum of the radius and the styloid process of the ulna There are six compartments beneath the dorsal carpal ligament, formed by the attachment of separate bands extending to the bones beneath Each compartment contains a synovial membrane The most lateral of the compartments contains the abductor pollicis longus and the extensor brevis Next lie the long and

*Further description of the fascial spaces and bursae is given in Chapter 12

runs in a groove between the head and styloid process of the ulna and inserts on the ulnar base of the fifth metacarpal

BACK OF THE FOREARM, DEEP GROUP—The deep group of muscles on the back of the forearm is composed of the supinator, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus and extensor indicis proprius

Origin and insertion—The supinator corresponds in a rough way in the upper forearm with the pronator quadratus in the lower forearm. It arises principally from the radial collateral ligament and the upper lateral surface of the ulna distal to the olecranon. The fibers sweep around the upper end of the radial shaft and the greater part of the muscle is inserted either into the lateral edge of the radial tuberosity or into the dorsal, medial and lateral surfaces of the body of the radius adjacent to it The deep branch of the radial nerve passes through the belly of the supinator muscle

The other four muscles of the deep group arise from the dorsal surface of approximately the middle three fifths of the radius and ulna and the corresponding part of the interosseous membrane

The abductor pollicis longus and extensor pollicis brevis tendons pass through a common groove and sheath on the lateral side of the lower end of the radius

The abductor pollicis longus is inserted into the base of the metacarpal of the thumb and the extensor pollicis brevis into the base of the proximal phalanx The extensor pollicis longus has a separate compartment in the dorsal carpal ligament and, after crossing the tendons of the extensor carpi radialis longus and brevis and the radial artery, inserts into the base of the distal phalanx of the thumb The extensor indicis proprius tendon parallels the long extensor of the thumb until it passes under the dorsal carpal ligament It then lies to the ulnar side of the extensor communis tendon of the index finger

The *anatomic snuffbox,* so often emphasized by anatomists of previous generations, lies between the extensor pollicis longus and the extensor pollicis brevis The radial artery runs through it When the hand is clenched, a groove can be seen running down the dorsum of the forearm from the lateral epicondyle to the styloid of the radius All the muscles lateral to this groove are extensors and all those medial are flexors On the volar surface a corresponding but less distant groove formed by the pronator teres can be seen extending from the medial epicondyle to the middle third of the lateral surface of the radius

to the sublimis group through the carpal canal into the hand to *insert on the terminal phalanges of the digits and thumb.* The tendons of the index finger and thumb may have a more or less common origin and this must be borne in mind in any surgical approach for tendon repair, because at times the tendons lie so closely together at the wrist that they appear to be a single tendon

The pronator quadratus is a short, flat, quadrilateral muscle extending across the lower part of the radius and ulna, and it has no tendon Except for the fact that it limits the dorsal spread of infection in the quadrilateral space in the forearm, it has little surgical significance

BACK OF THE FOREARM, SUPERFICIAL GROUP—The superficial group consists of the brachioradialis, extensor carpi radialis longus and brevis, extensor digitorum communis, extensor digiti quinti proprius and extensor carpi ulnaris

Origin—All these muscles, except the brachioradialis, have a common tendinous origin from the lateral epicondyle of the humerus This also receives fibers from the radial collateral ligament at the elbow and the antibrachial fascia and, like the common tendon of the medial epicondyle, forms prolongations into the forearm which become the intermuscular septa between the muscles The brachioradialis, the most superficial muscle of the group, arises slightly proximal to the lateral epicondyle on the upper two thirds of the lateral supracondylar ridge of the humerus

Insertion—The brachioradialis is inserted into the styloid process of the radius The extensor carpi radialis longus is inserted into the dorsal surface of the base of the second metacarpal bone, and the extensor brevis into the base of the third metacarpal bone These two tendons pass beneath the muscles and tendons of the thumb and have a common sheath where they pass under the dorsal carpal ligament The extensor digitorum communis tendons insert into the second and third phalanges of the fingers

On the back of the hand the tendons of the middle, ring and little fingers are connected by obliquely placed bands called the junctura tendinum When one common extensor tendon of these fingers is severed, the finger may still be extended by the tendon of the adjacent finger acting on it through these bands The extensor minimi digiti is often fixed with the belly of the extensor communis This tendon inserts into the dorsal aponeurosis with the communis tendon but has a separate compartment under the dorsal carpal ligament The extensor carpi ulnaris

runs in a groove between the head and styloid process of the ulna and inserts on the ulnar base of the fifth metacarpal

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TENDONS

The tendons which move the hand and fingers have their origin in the muscles in the forearm like the quill of a feather In the lower forearm they gradually lose their muscular surroundings and pass closely packed together in the space between the overlying fascia and the bones In this location the tendons obtain their blood supply from their muscles and are packed in a loose, fatty tissue which enables them to slide freely As they enter the hand at the wrist they pass under the transverse carpal ligament and here undergo some anatomic changes A mesotendon can be found in the carpal region carrying blood vessels to the tendons In the palm a branch of the deep carpal arch goes to each lumbrical muscle and to the tendons here In the fingers, where the tendons are ensheathed, the vincula each carry blood vessels to the tendons, and near their insertions the tendons again have a mesentery carrying good-sized vessels The tendon between these points carries a microscopic vessel along its dorsal surface or, in some places, only a few arterioles in the substance of the tendon itself (Fig 3)

In the palm the tendons separate from each other and pass along the metacarpals to the fingers Between each pair of tendons lie the digital artery and vein and the lumbricales muscle Deep to them are the interosseous membrane, the interosseous muscles and the metacarpals, and superficially the palmar fascia Any extra space here is filled with fatty areolar tissue In the distal half of the palm the tendons enter the dense digital sheaths The long flexor tendon to the thumb runs between the two heads of the flexor pollicis brevis It enters a sheath just proximal to the metacarpal head The overlying intrinsic muscles of the thumb and their nerve supply from the motor branch of the median nerve make this tendon relatively inaccessible to surgical approach in this region, though more proximally at the crease of the wrist it can be approached

Each *sublimis tendon* bifurcates opposite the base of the proximal bony phalanx, and the profundus tendon glides through the sublimis here The sublimis reunites after the profundus passes through it, and the sublimis then inserts into the sides of the middle phalanx The sublimis tendons at the wrist are arranged in pairs, those for the middle and ring fingers lying superficial to those for the index and little fingers The *profundus tendons* lie beneath the sublimis tendons throughout their length, being enveloped in the same synovial sac The index finger tendon is separate from the rest of the tendons throughout most of its length in the forearm, enabling this finger to be worked separately As the profundus tendons

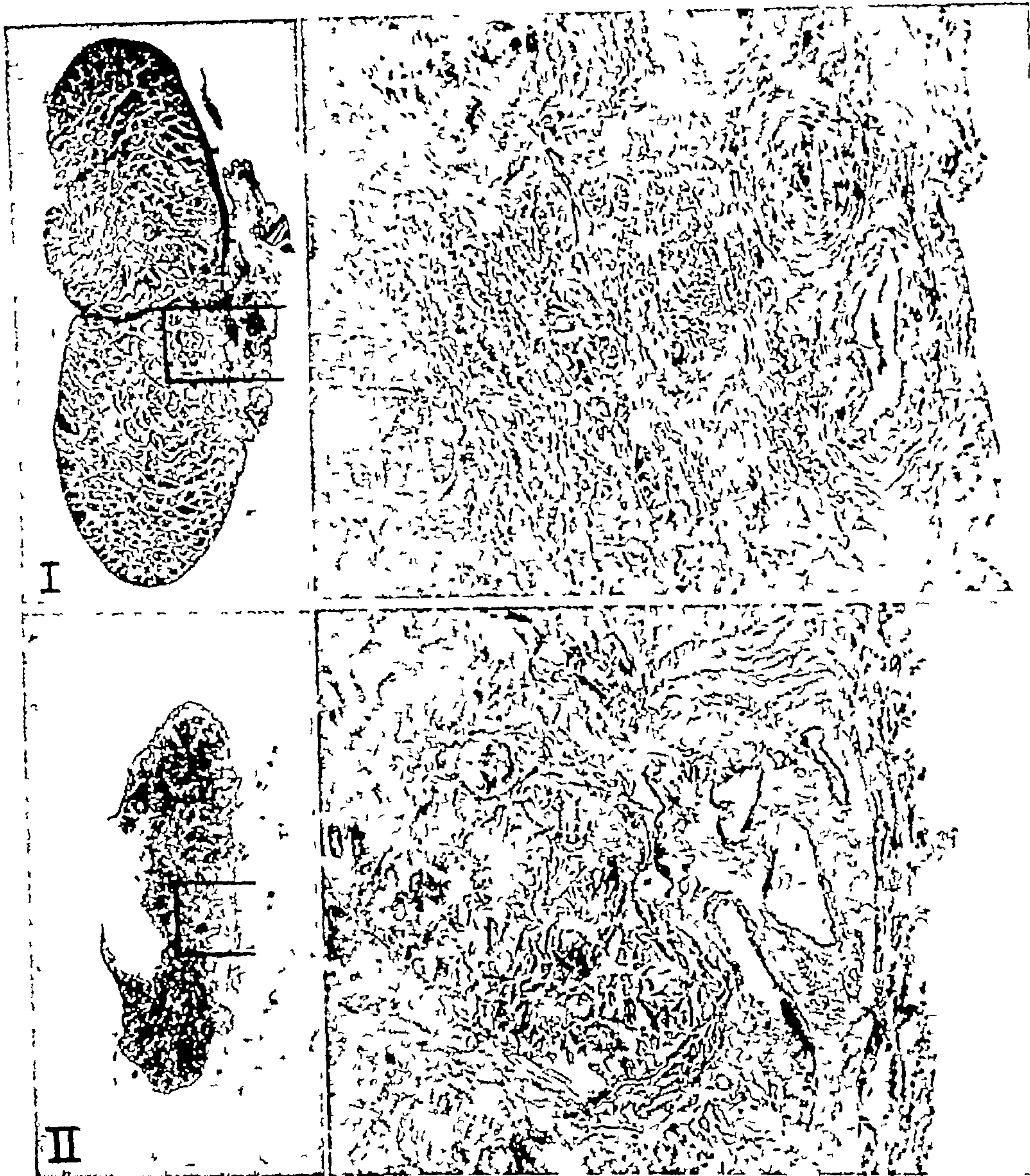


FIG 3 —Photomicrographs of blood supply in tendons, low power ×10, high power ×100 *I,* profundus tendon in middle segment of fourth finger vessels carried in mesentery on dorsal surface. *II,* profundus tendon in proximal segment of fifth finger longitudinal vessel in dorsal surface of tendon

pass through the sublimis tendons they are considerably narrowed, and that portion of the tendon passing through the middle segment of the finger is smaller than the part proximal to it The profundus tendons are inserted into a narrow triangular area on the proximal volar surface of the distal phalanges

The *extensor tendons,* after leaving their muscular surroundings on

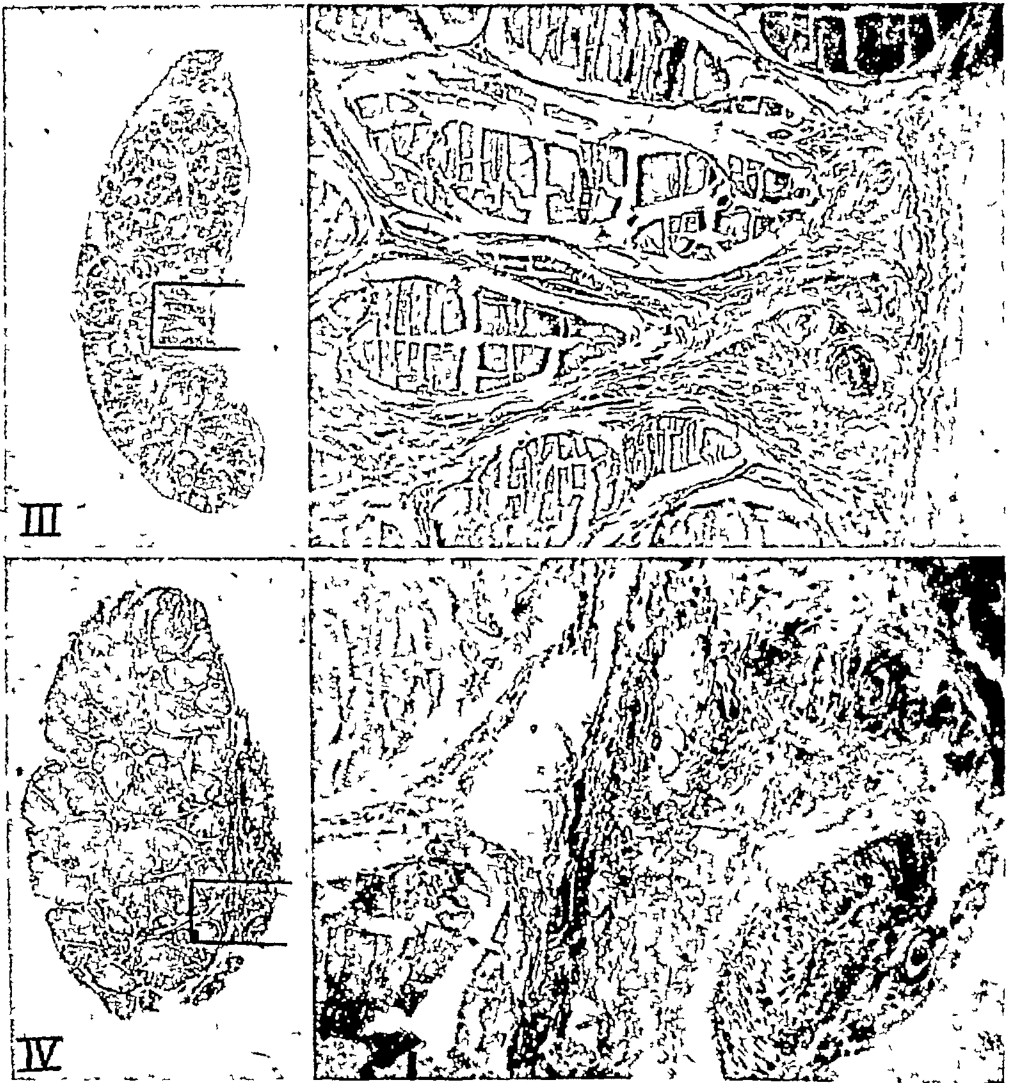


FIG 3 *(cont)*—*III,* sublimis tendon in proximal segment of long finger blood supply from mesentery on lateral edge, longitudinal vessel along center of dorsal surface *IV,* sublimis tendon in palm blood supply in mesentery on dorsal surface (From Nichols *et al* Am J Surg 87 379-383, 1954)

the back of the forearm, pass through separate compartments on the dorsum of the radius, passing under the dorsal carpal ligament, and then fan out over the dorsum of the hand Extensor tendons have no vinculae or mesentery except under the dorsal carpal ligament, their blood supply is derived from capillaries from the surrounding tissues In the forearm there are two groups a deep group composed of the abductors and extensors of the thumb and the extensor indicis proprius, and the super-

ficial group composed of the wrist extensors and the common extensors of the fingers, along with the proper extensor of the little finger At the wrist, however, the tendons all lie at about the same depth under the skin except that the radial extensors of the wrist pass under the thumb tendons and the extensor indicis proprius lies beneath the common extensors. As the tendons fan out on the back of the hand they become ovoid to flattened and finally, over the metacarpal heads, they form membranous expansions—the dorsal aponeuroses of the fingers (often called extensor aponeuroses)

The lateral borders of these *dorsal aponeuroses* receive the insertions

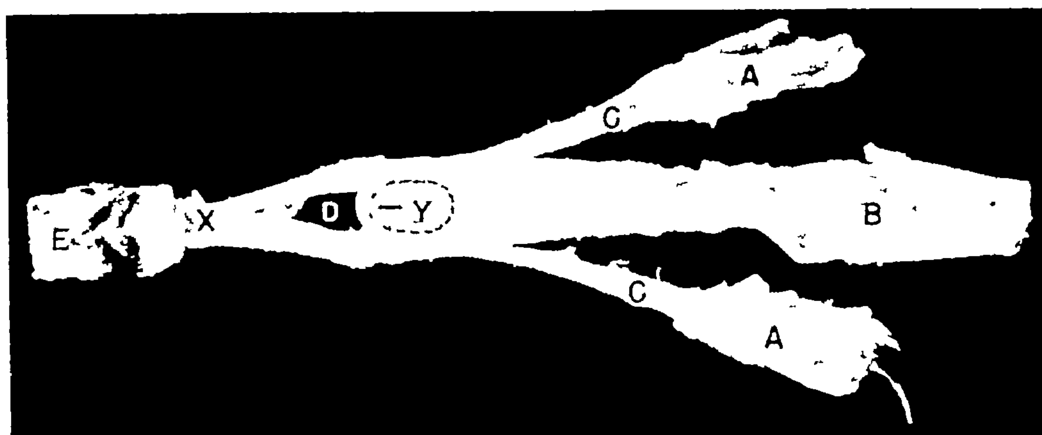


FIG 4—Palmar aspect of extensor mechanism of finger The triangular ligament over the interphalangeal joint and the aponeurosis over the metacarpophalangeal joint were removed to emphasize the tendinous structures Interosseous muscles and their insertions into the lateral bands are exposed *A*, interosseous muscles, *B*, extensor tendon over metacarpal, *C*, lateral bands, *D*, triangular membrane, *E*, terminal segment of finger, *X*, area torn in mallet finger, *Y*, area torn in central slip rupture (From Nichols J Bone & Joint Surg 33-A 836-841, 1951)

of the interossei and lumbricales The central tendinous portion of the tendon spreads as it passes down the dorsum of the proximal phalanx and a central slip is inserted into the proximal end of the middle phalanx. The lateral slips pass around the sides of the back of the middle joint and become reunited over the terminal joint In this location the tendon is thin and is easily injured just proximal to its insertion in the distal phalanx (Fig 4)

To understand the several functions of the *extensor mechanism*, it must be appreciated that the intrinsic muscles and the common extensor tendon working together can partially flex, extend or spread the fingers This is due to the shift of the aponeurosis that occurs when the extensor tendon is tensed or relaxed When tensed, the extensor tendon acting through its

lateral borders actually extends the whole finger and the interossei assume their function of abduction or adduction If the extensor tendon is relaxed or is severed, the extensor aponeurosis slides distally The intrinsic muscles through their insertion into the lateral bands are then able to extend the distal two joints of the fingers, although the proximal joints remain partially flexed The interossei can also act as flexors of the proximal joints when the flexor tendons are severed, although they have no flexing action on the distal two joints

SHORT MUSCLES OF THE HAND

The short muscles of the *little finger,* which constitute the hypothenar eminence, are the least important group They comprise the abductor, opponens and flexor digiti quinti brevis All arise from the pisiform and the hook of the hamate and adjacent ligamentous structures The abductor and flexor digiti quinti, more superficially placed, insert into the ulnar border of the proximal phalanx of the little finger The opponens lies deep beneath the other two and is inserted into the ulnar border of the distal three fourths of the fifth metacarpal These muscles are supplied by the ulnar nerve, and the action of the first two is to abduct or flex the little finger at its base The opponens helps to cup the palm

The short muscles of the *thumb,* constituting the thenar eminence, are best divided into two groups Those supplied by the median nerve are the abductor, opponens and lateral head of the flexor brevis, those supplied by the ulnar nerve are the ulnar head of the flexor brevis and the adductor obliquus and transversus The abductor, opponens and superficial part of the flexor brevis arise from the navicular, the greater multangular and the adjacent part of the transverse carpal ligament The abductor and the flexor brevis are inserted into the first phalanx of the thumb, whereas the opponens is inserted into the metacarpal * The deep or ulnar portion of the flexor brevis arises from the first metacarpal bone and is inserted into the ulnar side of the first phalanx of the thumb This muscle is analogous to the palmar interosseous muscles The adductor pollicis obliquus and transversus arise from the base and shaft respectively of the middle metacarpal, as well as adjacent ligamentous structures, and they both insert by tendons into the ulnar side of the base of the first phalanx of the thumb The short muscles of the thumb act synchronously to perform circumduction Those supplied by the ulnar nerve act princi-

*Daniel Riordan believes the abductor inserts into the extensor aponeurosis

pally in adduction and flexion, whereas those supplied by the median oppose, abduct and flex

The *interosseous muscles* occupy the spaces between the metacarpal bones. They are arranged in two sets, palmar and dorsal, depending on whether their origin is from the palmar or dorsal borders of the metacarpal shafts. Their insertions are exactly alike, all having tendons which pass behind the deep transverse metacarpal ligament and all inserting into the dorsal aponeuroses of the extensor tendons These muscles are all supplied by the ulnar nerve The palmar group, by being inserted into the ulnar side of the index finger and the radial sides of the ring and little finger, act as abductors, the dorsal group, by being inserted into the radial sides of the index and middle fingers and the ulnar sides of the middle and ring fingers, act as abductors

The *lumbrical muscles* are located deep in the palm between the flexor tendons They arise by one or two heads from the profundus tendons, pass in front of the transverse metacarpal ligaments through the lumbrical canals and are inserted into the radial sides of the dorsal aponeuroses. They are somewhat variable in number, and the nerve supply, although variable, is usually from the median nerve to the two lateral muscles and from the ulnar nerve to the two medial muscles The lumbricales have a moving origin as well as insertion, drawing the profundus tendon into the finger to allow free extension, aiding flexion of the proximal joint of the finger and aiding the interossei in extending the distal two joints when the extensor tendon is tensed

ARTERIES AND VEINS

Arterial blood is carried as far as the elbow by a single large vessel which arises from the aorta (right) or innominate artery (left), passes behind the scalenus anticus and then beneath the clavicle through the axilla and down the arm subcutaneously, medial to the biceps, and under the lacertus fibrosus to the forearm By its location it is called the subclavian, axillary or brachial artery At the level of the insertion of the biceps tendon it divides into the radial and ulnar arteries

The *subclavian vein* lies slightly below and anterior to the artery, and the axillary vein lies on the medial side of the artery, which it partly overlaps, the cord of the brachial plexus as well as the median, ulnar and median anterior thoracic nerves lying between the two vessels The two brachial veins are located on each side of the brachial artery As the veins emerge from under the lacertus fibrosus, they divide into the radial and ulnar veins

The *radial artery* extends from the neck of the radius to the styloid process, lying at first medial to the body of the bone and then anterior to it in its more distal portion In its upper third, the radial artery lies between the brachioradialis and the pronator teres, and in the lower two-thirds between the tendons of the brachioradialis and the flexor carpi radialis The sensory branch of the radial nerve is close to the lateral side of the artery The artery is accompanied by two venae comitantes This artery occupies a considerably more superficial position than the main nerves in the forearm In the wrist the artery turns laterally, passing under the tendons of the abductor pollicis longus and extensor pollicis brevis and lying against the ligament of the wrist joint It then passes under the extensor pollicis longus and over the carpal bones proximal to the thumb and dives into the cleft between the bases of the metacarpals of the thumb and index finger, passing between the heads of the first dorsal interosseous muscle It then passes transversely across the palm, piercing the adductor pollicis muscles, and ends at the base of the metacarpal of the little finger where it anastamoses with the deep branches of the ulnar artery to complete *the deep volar arch*

The *ulnar artery* is slightly larger than the radial From its origin near the biceps tendon it passes under the median nerve to the ulnar side of the arm, and at about the upper third of the forearm it comes to lie against the ulnar nerve, which it accompanies throughout the rest of the arm In its upper half it is covered by the muscles arising from the median epicondyle—the superficial group of flexor muscles In the lower half of the forearm it is covered by the deep fascia and is placed between the flexor carpi ulnaris and the flexor digitorum sublimis It is accompanied by two venae comitantes At the wrist the ulnar artery is covered only by skin and the volar carpal ligament and lies on the transverse carpal ligament The pisiform bone lies just ulnar to it and the ulnar nerve just behind it. The artery first gives off a branch which passes through the muscles of the little finger into the deepest layer of the palm of the hand This deep volar branch connects directly with the deep volar arch The terminal portion of the ulnar artery forms the *superficial volar (palmar) arch* This crosses the transverse carpal ligament and then lies on the tendons and nerves in the palm deep to the palmar fascia. The superficial palmar arch lies at about the level of the crease of the extended thumb, and the deep volar arch is about ½ in proximal to it

A superficial volar branch arises from the radial artery just proximal to the transverse carpal ligament and passes across the short thumb muscles to the terminal portion of the superficial volar arch of the ulnar

artery, thus completing the superficial volar arch This vessel is usually small The superficial volar arch gives off four *common volar digital arteries,* which arise from the convexity of the arch and extend toward the distal portion of the palm lying on the lumbrical muscles

About ½ in proximal to the webs of the fingers, these digital arteries receive a branch from the deep volar arch and then fork into a pair of *proper volar digital arteries,* which run along the contiguous sides of the index, middle, ring and little fingers behind the corresponding digital nerves The common volar branch to the thumb is called the *princeps pollicis* and it, with the branch to the radial side of the index finger, arises from the deep volar arch and lies beneath the adductor pollicis muscles

The deep *veins* of the forearm and hand are not nearly as capacious as the superficial veins The latter form a network over the hand and forearm, lying beneath the skin between the two layers of the superficial fascia At the elbow two main venous channels are formed, the cephalic and basilic The cephalic vein ascends in the groove along the lateral borders of the biceps and passes between the pectoralis major and the deltoid, ending in the axillary vein just below the clavical The basilic vein ascends in the groove between the biceps tendon and the pronator teres and then runs up the medial borders of the biceps to join the brachial vein as it enters the axilla

NERVES

The principal nerves of the hand are the median and ulnar. The radial nerve simply supplies sensation to the dorsum of the index finger and thumb Its more important function is supplying the extensor muscles of the wrist and digits through its motor branch, which arises at the elbow

MEDIAN NERVE—This nerve arises from the lateral and medial cord of the brachial plexus, fibers derived from the sixth, seventh and eighth cervical and first thoracic nerves In the arm it at first lies lateral to the brachial artery, at about the level of the middle of the humerus it crosses the artery and lies on its medial side at the bend of the elbow Here it is situated behind the lacertus fibrosus and in front of the brachialis muscle It *enters the forearm* by passing between the two heads of the pronator teres, being separated from the ulnar artery, which it crosses, by the deep head of the pronator teres It then proceeds down the middle of the forearm, lying beneath the flexor digitorum sublimis and on top of the flexor digitorum profundus The muscular branches to the superficial muscles arise near the elbow, separate branches going to each of the superficial muscles except the flexor carpi ulnaris, which is supplied by the ulnar

nerve The volar interosseous branch (deep branch, Fig 5) of the median, which arises 2 or 3 in distal to the elbow, supplies all of the deep muscles of the forearm except the ulnar head of the flexor digitorum profundus

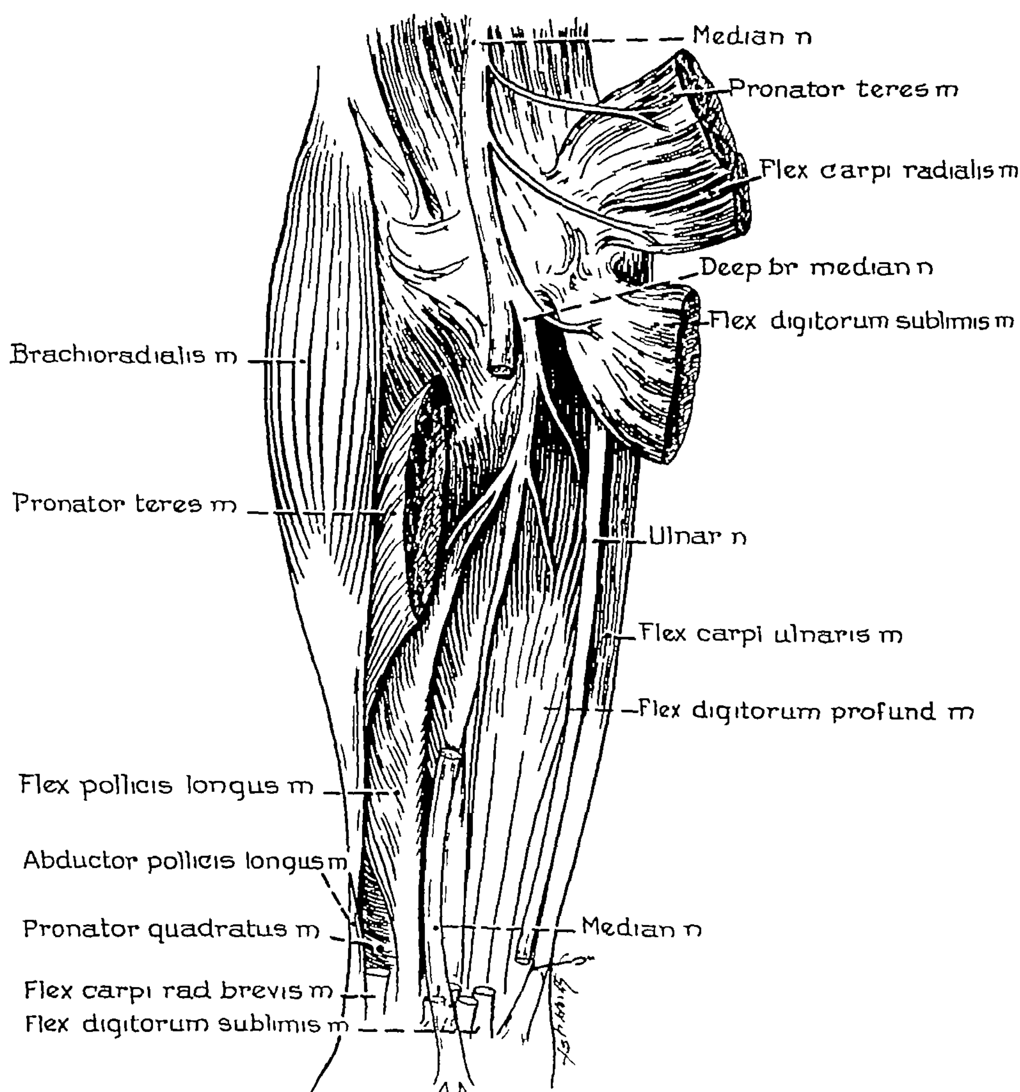


FIG 5 —Deep branch of median nerve (sometimes called volar interosseus branch)

About 2 in proximal to the transverse carpal ligament the median nerve becomes more superficial, lying behind the tendon of the palmaris longus and to the ulnar side of the flexor carpi radialis A small palmar branch given off in this location traverses the transverse carpal ligament, dividing into a medial and a lateral branch The lateral branch supplies

the skin of the base of the thumb and the medial branch supplies the skin of the palm

The main trunk of the median nerve *enters the palm* by passing under the transverse carpal ligament. Here it lies superficial to the tendons Under the distal portion of the transverse carpal ligament the nerve divides into a lateral and medial portion. The lateral portion contains the muscular branches to the abductor brevis, opponens and the superficial head of the flexor brevis of the thumb and the sensory branches which supply the sides of the thumb and the radial side of the index finger The nerve to the first lumbrical muscle accompanies the latter sensory branch. The medial portion of the nerve divides into two common volar digital nerves, one of which supplies the adjacent sides of the index and middle fingers, and the other the adjacent sides of the middle and ring fingers The nerve to the second lumbrical muscle accompanies the volar digital nerve to the second cleft As these nerves lie in the palm, they are superficial to the lumbrical muscles and tendons but deep to the branches of the superficial palmar arch As they enter the fingers, the nerves and arteries pass volar to the muscles and in the fingers the nerves lie superficial to the vessels At the ends of the fingers the nerve is split into two branches, one of which supplies the pulp of the finger and the other the soft tissues beneath the nail

ULNAR NERVE—The ulnar nerve derives its fibers from the eighth cervical and first thoracic nerves by way of the medial cord of the brachial plexus It lies medial to the axillary and brachial arteries as far as the middle of the arm and then pierces the medial intermuscular septum and passes along the triceps to the groove between the medial epicondyle and the trochlea of the humerus It lies medial to the joint capsule here The nerve enters the forearm between the two heads of the flexor carpi ulnaris It accompanies the ulnar artery, lying beneath the superficial muscles and on top of the flexor digitorum profundus It lies at the same depth in the muscle bellies as the median nerve but in a more ulnar position In the upper forearm it is covered by the flexor carpi ulnaris, and about half way down the arm it becomes superficial, lying under the edge of this muscle, the flexor digitorum sublimis occupying a more radial position in the arm From the middle of the forearm to the wrist the nerve lies behind and to the ulnar side of the ulnar artery

The only branches of any importance in the forearm are the two muscular branches arising near the elbow, which supply the flexor carpi ulnaris and the ulnar half of the flexor digitorum profundus, and two sensory branches The *dorsal sensory branch* arises about 5 cm above the

wrist, passes backward beneath the flexor carpi ulnaris and supplies the integument on the ulnar half of the dorsum of the hand This branch anastomoses freely with the sensory branch of the radial nerve

The *palmar cutaneous branch* of the ulnar nerve arises in the middle of the forearm, descends on the ulnar artery and ends in the skin of the palm This branch anastomoses with the palmar cutaneous branch of the median nerve

Just proximal to the wrist the *main trunk* of the ulnar nerve emerges from the deep fascia and, with the ulnar artery, passes across the top of the transverse carpal ligament into the palm In passing the pisiform it lies just beneath the artery and just radial to this bone Just distal to the pisiform the muscular and sensory components separate The *muscular branch* first gives off fibers to the hypothenar muscles and then passes through the origin of these muscles around the ulnar border of the hook of the hamate and, accompanying the deep branch of the ulnar artery to the deep palmar arch, crosses the palm, giving off separate branches to each of the interosseous muscles and to the two adductor muscles and the ulnar head of the flexor pollicis brevis The *sensory branch* divides into two branches a short distance distal to the transverse carpal ligament One of these branches passes to the ulnar side of the little finger, lying throughout the palm on the flexor brevis muscle of the little finger The other branch runs straight down the palm to the cleft between the ring and little fingers, supplying their adjacent sides

RADIAL NERVE—The radial nerve is derived from the fifth, sixth, seventh and eighth cervical and first thoracic nerves by way of the posterior cord of the plexus It descends behind the artery and winds around the humerus, passing first posteriorly at about its middle third, where it gives off branches to the triceps, and then anteriorly to the front of the lateral epicondyle where it lies lateral to the long head of the biceps At this point it divides into two branches, a superficial sensory branch and a deep muscular branch (Fig 6)

The *superficial branch* lies beneath the brachioradialis and slightly lateral to the radial artery in the upper forearm and at about the middle of the arm passes beneath the muscle It then becomes superficial, lying alongside the adductor and extensor pollicis tendons at the wrist, and ends by supplying the radial half of the dorsum of the hand and wrist The *deep branch* winds to the back of the forearm around the lateral side of the neck of the radius between the two planes of the fibers of the supinator and extends downward between the deep and superficial muscles of the dorsum of the forearm This branch supplies the extensors of the

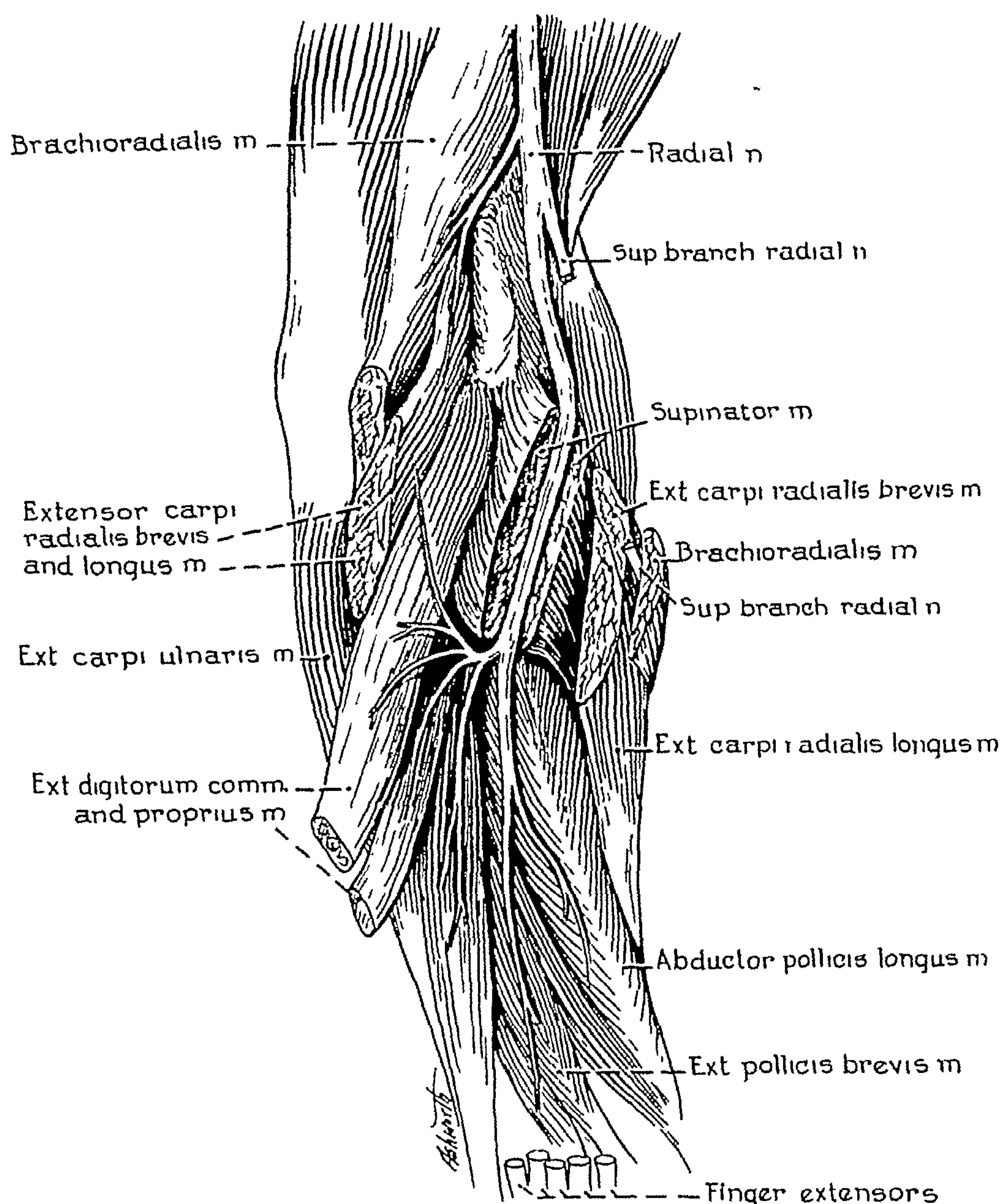


FIG 6—Deep branch of radial nerve

fingers, thumb and wrist except for the extensor carpi radialis and brachioradialis, which are supplied by branches coming from the radial nerve above the elbow.

BONES AND JOINTS

The bony skeleton of the hand consists of five rays of metacarpals and phalanges fastened to the carpal bones at their bases. The carpal bones form a double-rowed arch of blocks across the base of the hand, giving

concavity to the palm, forming a channel for the flexor tendons and supporting the metacarpals in a radial arrangement The metacarpals of the fingers are fanned out from the distal side of the arch, and the metacarpal of the thumb is fastened by a swivel-like joint to one end of the arch, allowing it to be extended parallel to the fingers or to be brought around to oppose the fingers The metacarpals and phalanges all have a slight arch toward the palm Their length and thickness decrease about a third each from the metacarpals to the end phalanges (Fig 7).

The *metacarpals and phalanges* are fastened together by hingelike joints, permitting a considerable amount of motion The interphalangeal joints are like miniature knee joints, allowing flexion and extension but no lateral motion In moving, the distal bone glides around the head of the proximal one The metacarpophalangeal joints are condyloid, the rounded heads of the metacarpals fitting into the concave ends of their phalanges This arrangement permits some lateral as well as extensive anteroposterior motion Each of these small joints has a heavy volar and two strong collateral ligaments The dorsal ligament is replaced by the extensor tendon

The metacarpal bones of the fingers come together and interlock with each other as well as with the carpal bones at their bases These joints are arthrodial, allowing only a small amount of gliding motion for the little finger, less for the others and almost none for the index finger The metacarpal of the thumb articulates separately with the great multangular by a saddle-type joint This not only allows motion in the anteroposterior and lateral planes but also allows rotation, so that the thumb can be brought around into opposition The other joints of the thumb are essentially the same as those in the fingers

The *carpal bones* are six sided and are arranged in two rows The distal row supports the bases of the metacarpals and provides the bony projections to which are anchored the transverse carpal ligaments The proximal row articulates with the radius to form the true wrist joint Between the proximal and distal rows there is an irregular S-shaped joint Lateral motion of the hand at the wrist takes place in this joint by a complex motion in which one row of carpals rotates anteriorly on the other but, due to the obliquity of the joint, lateral motion results

The *wrist joint* proper is between the distal end of the radius and the navicular, lunate and the radial half of the triangular bones The lower articulating surface of the radius is rather concave and about two-thirds as deep as it is broad The radial articulating surface of the three carpal bones forms a quadrant of a circle, the center of which lies about 1 in

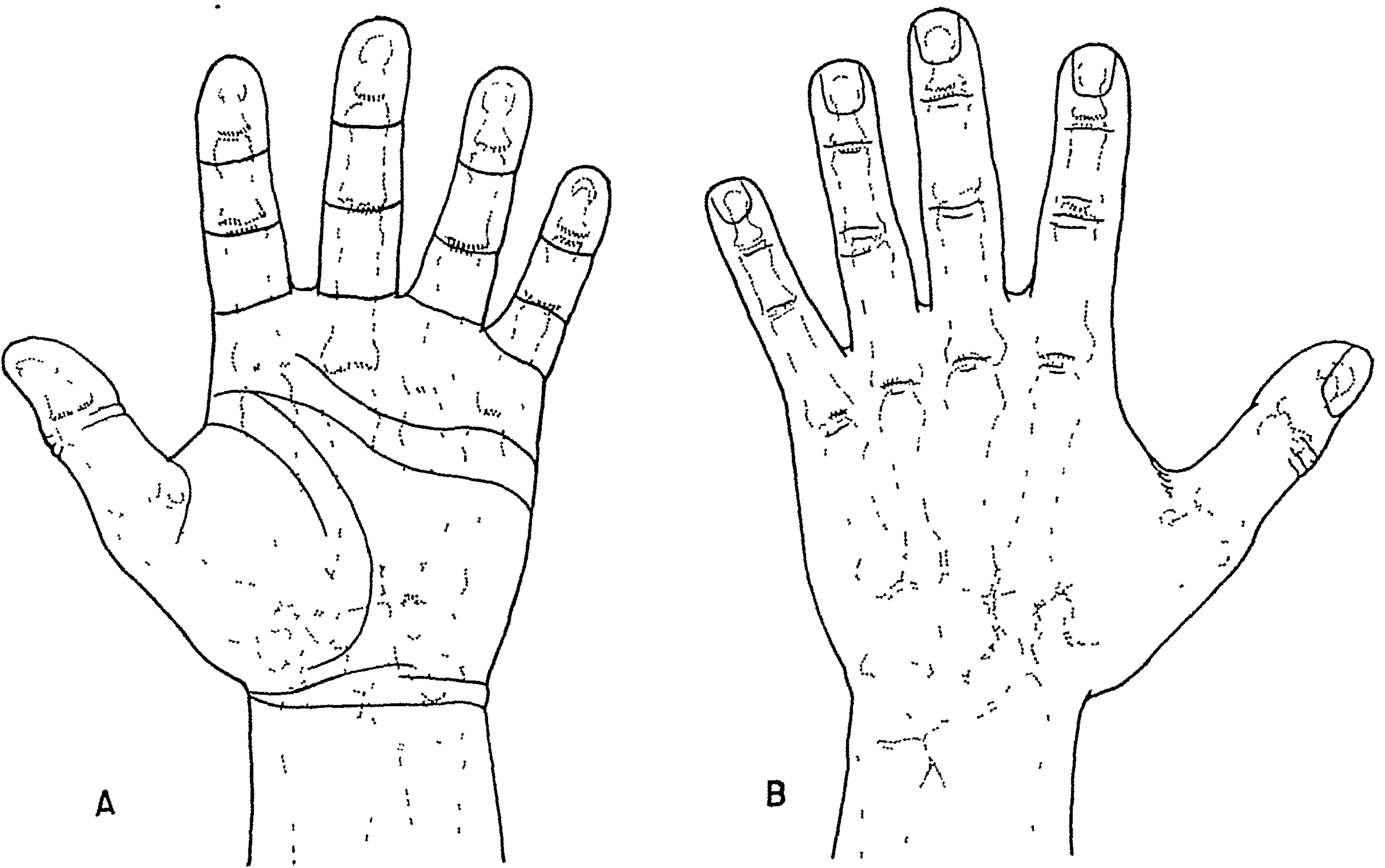


FIG 7 —Relationship of bones and joints to surface landmarks of the hand (composite made from x-ray studies) *A*, volar, *B*, dorsal

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CHAPTER TWO

General Technic; Preoperative and Postoperative Care

FIRST AID

PROTECTION IS the keynote for first aid care of hand wounds Further contamination, added injury or meddlesome probing are all interdicted Sterile protective dressing with firm compression and splinting to immobilize the extremity in a comfortable position (usually the position of function) is all that is necessary in order to transport the patient to an adequately equipped surgery

PREOPERATIVE CARE

SHOCK —In hand injuries which are not complicated by wounds elsewhere on the body, shock is not a critical factor If the patient has been in good health, even a traumatic amputation of the forearm will usually not produce severe shock However, if much blood has been lost and the operative procedure contemplated is going to be a long one, it is well to type and cross-match the blood and to have blood available Use of a tourniquet during the operation prevents additional blood loss If surgery is to be done on a patient who is a bleeder or who has a primary or secondary anemia, blood should be given The only contraindication to early operation is severe shock from blood loss when there is no blood available for replacement Patients who are in shock should not be given a general anesthetic until blood transfusion is started, without it, anesthesia is rendered more difficult and may be exceedingly risky

PREMEDICATION —Morphine and atropine, or comparable drugs,

away in the distal third of the capitate When the wrist is posed so that the carpal canal is straight with the long axis of the radius, the arching structure of the second row of the carpal bones is tilted slightly backward, thus the metacarpals are tilted slightly dorsally. This is the strongest position of the hand Motion at the radiocarpal joint is almost all flexion and extension.

The *bones of the forearm* are roughly one and one-half times the length of the hand. In the supinated position, the radius and ulna bow away from each other slightly. Both bones have a slight ventral concavity The radius thickens gradually to its distal end, which is cut off in a roughly triangular way with a tilting of 15–20 degrees toward the ulnar side and 3–5 degrees toward the palm of the hand The dorsal and lateral sides of the distal end of the radius are furrowed by three deep grooves for the tendons of the extensors of the digits, extensors of the wrist and the abductors of the thumb, respectively On the ventral surface where the tendons funnel through the carpal canal no grooves are present The ligaments around the wrist are very strong and those around the carpal bones overlap each other, making a strong, continuous, ligamentous structure which extends from the distal radius and the ulna to the metacarpal bases Structurally, these joints are divided into three distinct synovial sections, the radiocarpal joint, the inferior radioulnar joint and the intercarpal joint The synovial sac of the intercarpal frequently continues with the carpometacarpal joints of the second, third, fourth and fifth metacarpal bones There is little rotation at the wrist, this motion being accomplished in the forearm by the radius rotating around the ulna The wrist then acts as a universal joint, transmitting this rotatory motion to the finger tips

The two bones of the forearm articulate with each other at each end by pivot-type joints At the elbow the head and neck of the radius are held in place by the tremendously strong annular ligament, which grasps the neck of the radius and allows the entire radius to pivot through an arc of 180 degrees When the forearm is pronated, the radius swings around the ulna, being attached to it by the interosseous membrane and by the distal radioulnar ligaments and the triangular fibrocartilage The *elbow* is a giglymus or hinge joint, the trochlea or pulley of the humerus fitting into the semilunar notch of the ulna, and the capitellum of the humerus articulating with the cup-shaped depression on the proximal end of the head of the radius The ligaments about the joint consist of the radial and ulnar collateral ligaments and the joint capsule

geon of his own limitations and honesty in not trying to accomplish the impossible (for him) will do much toward making a satisfied patient and not a psychiatric problem

ANESTHESIA

The anesthesia used in hand injuries may be local, regional or general If facilities are equally good, the choice may be a matter of the patient's or the physician's preference Local or regional anesthesia is mandatory if the patient has just eaten or if there is a pulmonary condition which contraindicates general anesthesia Simple procedures such as skin grafting of small areas, repair of lacerations, minor amputations, some tendon repairs and treatment of simple fractures or dislocations are easily done under local anesthesia.

General anesthesia is preferred for treatment of multiple nerve and tendon injuries, complicated fractures, avulsions of soft tissue requiring extensive skin grafts or flaps and major amputations When a trained anesthesiologist is available, regional anesthesia may be used for these complicated cases Regional anesthesia may also be adopted by the operator if he perfects himself in the technic of administration and understands its limitations The chief limitation of regional anesthesia is that the anesthetic often wears off before a prolonged procedure is completed This necessitates supplementing the anesthesia by changing over to a general anesthetic in the middle of the operation or by using local anesthesia at the site of the wound During the later stages of the operation, when the anesthesia is deteriorating, the patient may be most uncomfortable and his restlessness may interfere with the operation

Local Anesthesia

Local anesthesia is produced by injecting procaine hydrochloride into the tissues around the site of the injury For most minor injuries it is the method of choice If a few basic rules are followed no complications need be feared

Whether 1 or 2 per cent procaine is used does not seem to matter greatly, if properly used, the 1 per cent solution is usually adequate The procaine should be *injected through intact, sterilized skin surrounding the wound.* In injections into the edges of a laceration, only one or two needle punctures are necessary A wheal is raised at one end of the wound with a 25 or 28 gauge needle A 20 or 22 gauge needle of a length which corresponds to that of the wound can be introduced through this wheal

should be administered preoperatively. They may be given intravenously if immediate anesthesia is contemplated

The patient should always be interrogated as to when he last ate and what was eaten and exactly when the accident occurred It is a serious mistake to give a general anesthetic to a patient with a full stomach. About four hours is required for digestion to empty the stomach under normal conditions, and if the accident happens soon after eating, digestion is delayed so that even after several hours the stomach may be full of food Under these circumstances it may be better either to postpone operation or to use local or regional anesthesia, unless the stomach can be completely emptied by aspiration

HAND INJURY RECORDS—Records of injuries are often neglected This is poor medical practice If hand injuries were routinely photographed and x-rayed preoperatively, a great deal of valuable clinical material would be collected The common practice of doing amputations without preoperative x-rays is mentioned to be condemned Under no circumstance should a patient be anesthetized before some examination has been made to ascertain the integrity of the bones, nerves and tendons of the hand

A simple method of insuring accurate records is to x-ray the hand and then to make a sketch of it, labeling the injuries as they are sketched in

DOCTOR-PATIENT RELATIONSHIP—"The art of communication is an essential ingredient of the art of medicine" In this way Arthur Sutherland of New York, in describing the psychiatric problems of the cancer patient, stressed the need of good rapport between patient and surgeon In hand injuries the patient finds himself faced with unexpected mutilation A little time spent in explaining things to him, at his own mental level, is often as important to successful treatment as the technic The surgeon must not only inspire confidence and trust from the first but must also listen to complaints later, after healing occurs Finally, he must guide the patient in the use of the damaged extremity

Often one sees patients whose complaints after a hand injury border on the psychiatric. Grossly exaggerated and bizarre complaints are common Hands are sometimes damaged, apparently accidentally, by patients with unstable mental backgrounds and suicidal tendencies Some of these patients are very difficult to treat Frequently the patient is foolish, ignorant and superstitious For successful treatment, the surgeon must evaluate the patient as well as his injured hand and care for him accordingly

A careful study of the injury with a clear, unambiguous recommendation will do much to inspire confidence Also, a recognition by the sur-

needle is inserted through a skin wheal into the fracture hematoma, and aspiration of dark blood confirms that the needle is in place Then 10 or 15 cc of procaine is injected Good anesthesia lasting about one-half hour will be obtained in a few minutes. Although tendons are insensitive, the manipulation of a tendon frequently throws its muscle into spasm. This can be partially corrected in a co-operative patient who can be taught to relax the muscle or muscles involved Injection of procaine into the muscles to relax them has not been found of much value. In some patients the reciprocal innervation of muscles can be utilized; for example, active extension relaxes the flexors In others, this movement tenses all muscles and the spasm can be avoided by asking the patient to relax

Limitations—The principal disadvantages of this technic are the increased technical difficulties involved, the psychologic strain on the patient and the pain from the tourniquet A tourniquet may be used for short procedures but inevitably causes pain if left on for more than an hour The patient becomes increasingly restless and has a dull, aching sensation throughout the arm

The amount of anesthetic solution injected does not seem to bear much relation to wound healing, provided too much is not injected into one area. If epinephrine is added to the procaine solution, a wise rule to follow is to use no more than 3 drops to the ounce for small quantities of procaine and not over 10–12 drops no matter how much procaine is used.*

Additional drawbacks to the use of local anesthesia are the multiple needle puncture wounds in the tissue, the increased trauma resulting from handling tendons against resistance and the tendency to make incomplete debridements and incomplete repairs due to inadequate hemostasis from tourniquet failure

Regional Anesthesia

Regional anesthesia is a modification of local anesthesia which consists of the blocking of regional nerves This may be done in a variety of ways, depending on the area for which anesthesia is desirable The usual locations are in digits and palm and at the wrist, elbow and brachial plexus.

Digital block.—A needle is introduced into the dorsolateral aspect of the finger just distal to the web (Fig 9) A wheal is made in this location on each side The needle is then introduced in a vertical direction toward the palmar surface of the finger, inclining it slightly medially toward the proper digital nerve This nerve lies in the fat at about ¼–⅛

*Because epinephrine with local anesthesia may cause vascular shut-down, some authorities oppose its use

and both sides of the wound separately anesthetized Enough procaine may be injected anywhere about the hand to balloon up the tissues a little without damage, but the tissues should not be "pumped full" To anesthetize a digit, a *ring* of anesthesia is injected proximal to the point of injury (Fig 8) The entire circumference of the finger is anesthetized Since the palmar surface of the finger and the palm of the hand are more sensitive than the dorsum, it is better to make a primary puncture wound on the dorsum of the finger or hand and then to run the needle through toward the palm, anesthetizing from the inside out at first and later introducing more anesthetic from the palmar surface as necessary.

Certain regions, particularly that around the nail and the distal pulp space of the fingers, are more difficult to anesthetize than others The nail area can be anesthetized by injecting the solution into the fold around the

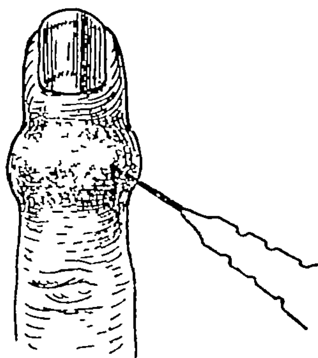


FIG 8 —Ring block anesthesia in digit.

nail and then introducing some anesthetic beneath the nail into the nail bed The distal pulp cannot be anesthetized directly without some pain This area can easily be anesthetized by making a ring directly proximal to it

Forearm wounds of the simpler types are easily handled using local anesthesia and even complicated wounds can be successfully managed if the patient is co-operative and if the operator avoids rough or painful manipulations Sensitive tissues around blood vessels and nerves may be infiltrated with the anesthetic solution and then become easily managed The injection of a drop or so of procaine into the adventitia of the blood vessel will stop pain from this source Bones are ordinarily insensitive but the periosteum surrounding them is sensitive and painful when manipulated

Local anesthesia for fractures—Injection is made directly into the fracture site and also into the periosteum around the fracture A 20 gauge

occasionally helpful to supplement a block at the wrist, elbow or brachial plexus which gives incomplete anesthesia It is easier to block the major nerves at the wrist, and no more complications are produced here than in the palm

NERVE BLOCK IN WRIST.—Injection into the nerves in the wrist is made approximately at the level of the proximal flexion crease of the wrist The operator holds three fingers of his hand in a row and places them so that the middle finger tip is about in the center of the wrist on the line of the crease This gives the approximate locations for injection into the median, ulnar and palmar cutaneous branches of these nerves (Fig 12). With a short 25 gauge needle, injection is first made into the median nerve The needle is introduced perpendicularly and the patient



FIG 11 —Gangrene of side of finger after digital block for paronychia

asked to indicate when he feels a twinge of pain in the median area Two to 5 cc of procaine is then injected A similar dose in the ulnar nerve and in the radial region should completely anesthetize the palm

This regional block does not anesthetize the back of the hand, and anesthesia is sometimes incomplete If the operator does not object to using a little supplementary local anesthesia, this is probably the method of choice to anesthetize the palm only.

NERVE BLOCK AT WRIST AND ELBOW (BUNNELL) —This method involves blocking the median nerve at the wrist, the ulnar nerve at the elbow and the radial fibers as they fan out over the dorsum of the thumb (Fig 13)

A wheal is first made at the wrist, using the proximal flexion crease and the palmaris longus and flexor carpi radialis as landmarks The needle is advanced through this wheal toward the median nerve until the patient

in depth from the anterolateral margin of the finger Two or 3 cc of procaine solution is introduced on each side, and several minutes are allowed to elapse before testing the end of the finger to see if anesthesia has been produced If anesthesia is incomplete, the dose may be repeated With this method, a tourniquet may be used on the base of the finger provided epinephrine is not used and the tourniquet is not on too long

The method is not without danger, although it is much used Gangrene of the finger has resulted, apparently from direct interference with the arterial blood supply (Fig 11) Incomplete anesthesia is common, especially of the region of the nail bed

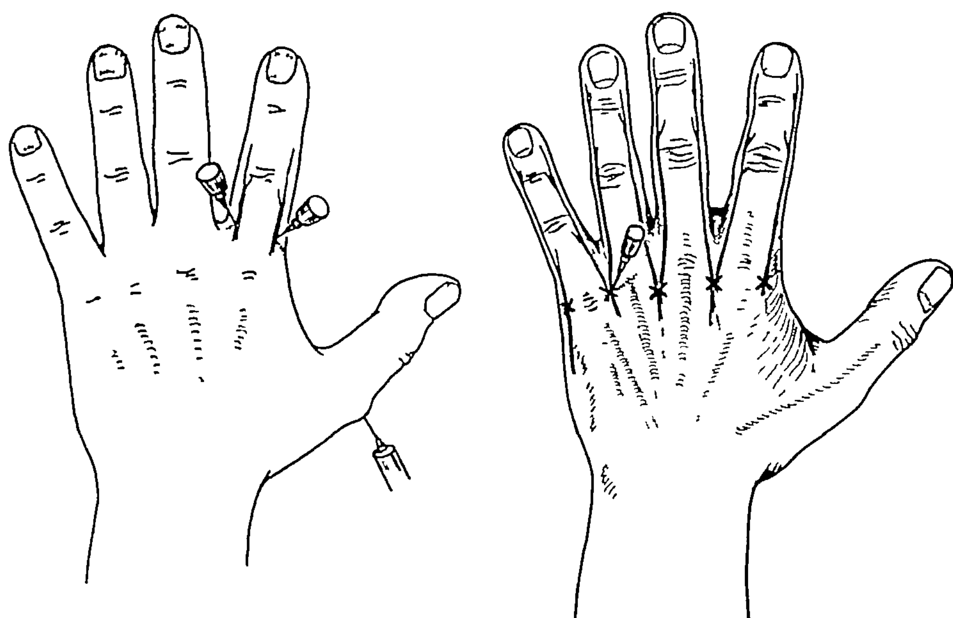


FIG 9 *(left)* —Blocking digital nerves at base of finger
FIG 10 *(right)* —Blocking digital nerves in hand

Digital block is indicated when injection of anesthesia distalward is contraindicated in the presence of certain localizing infections and occasionally with scattered or extensive wounds It is definitely contraindicated in spreading infections and crushing injuries

NERVE BLOCK IN PALM —Skin wheals are made over the dorsum of the metacarpals at approximately the level of their necks (Fig 10). A needle is introduced through the wheal and advanced toward the palm for about ¾ in Injection of 5–7 cc of procaine solution in each area should anesthetize the adjacent sides of the fingers distal to the injection site This method is said to be safer than digital block in the fingers and is

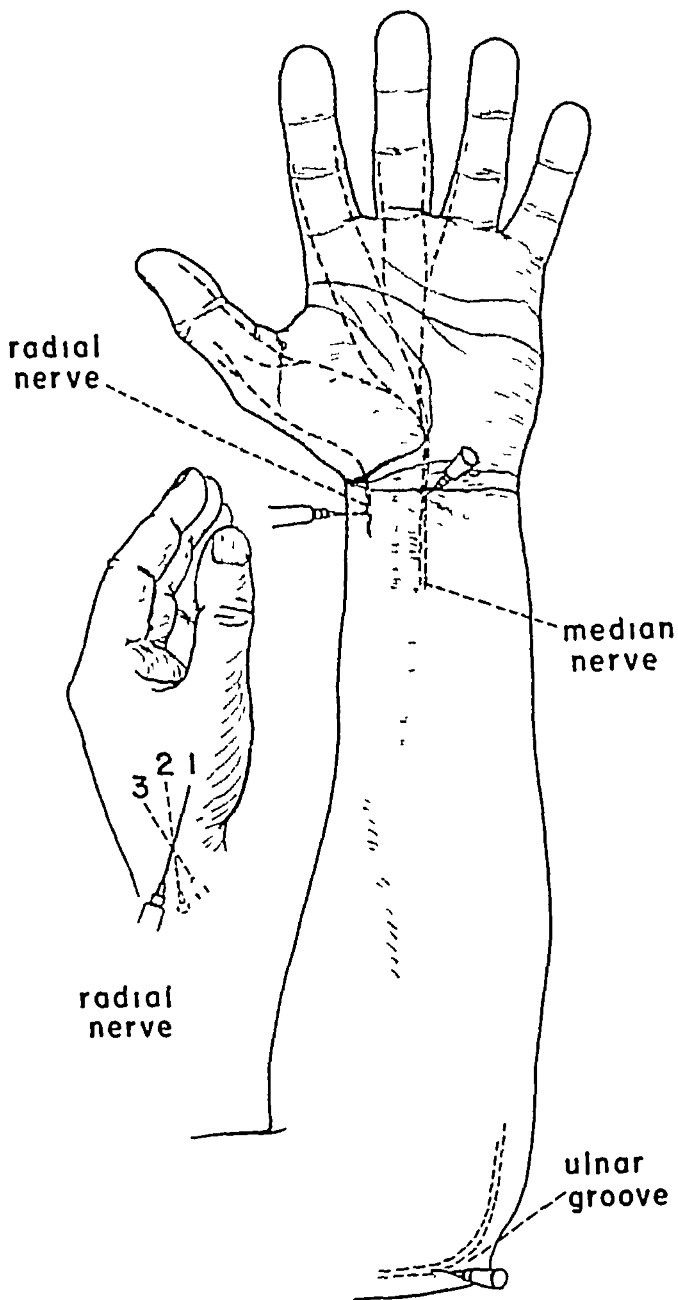


FIG 13 —Blocking median and radial nerves at wrist and ulnar nerve just above elbow This is one of the best methods for anesthetizing the hand

reports a twinge of pain in the median area. Injection of 3–5 cc. of procaine is then made A wheal is next made just proximal to the ulnar groove of the median epicondyle of the humerus. The needle is introduced and when the patient indicates he feels a twinge of pain in the ulnar area, 2–5 cc of procaine is injected here Branches of the radial nerve are anesthetized by advancing the needle over the dorsolateral aspect of the distal end of the radius into the subcutaneous plane and injecting 5–10 cc of procaine here Bunnell used 2 per cent procaine with epinephrine,

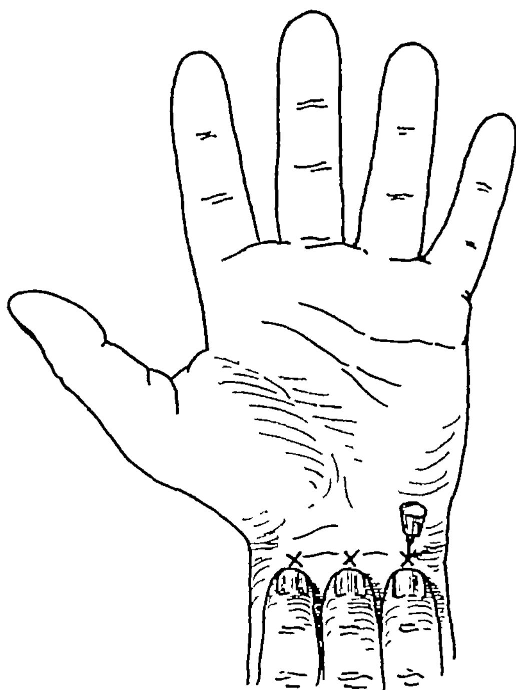


FIG 12 —Wrist block for anesthesia of palm

3 drops to the ounce, for block anesthesia but does not believe that epinephrine should be used distal to the palm

BRACHIAL PLEXUS BLOCK —With the patient supine and the arm pulled down at the side, a needle is introduced above the center of the clavicle and aimed to strike the first rib The needle is then withdrawn and made to progress up the rib, feeling for the cords of the plexus As the cords are encountered, paresthesias in the corresponding parts of the extremity will be elicited For the three cords, a total of about 20 cc. of 2 per cent procaine is used with a proportional amount of epinephrine or Cobefrin

This method should not be used except by one skilled in anesthesiology

A few specialized bone instruments are occasionally required. A small drill should be at hand when it is necessary to pass wires through bones. A miniature Sherman plate is available which requires an especially small drill for the tiny screws that hold it in place. There is also a special type of drill to use for intramedullary fixation with Kirschner wires Special clamps to hold bones and plates together are not necessary, either towel clips or the fingers can be used A muscle dissector with a slightly curved end, a small periosteal elevator and several small chisels may be useful

SUTURE MATERIAL—The choice of ligature and suture material follows the basic principles of plastic surgery In the hand, whatever is used

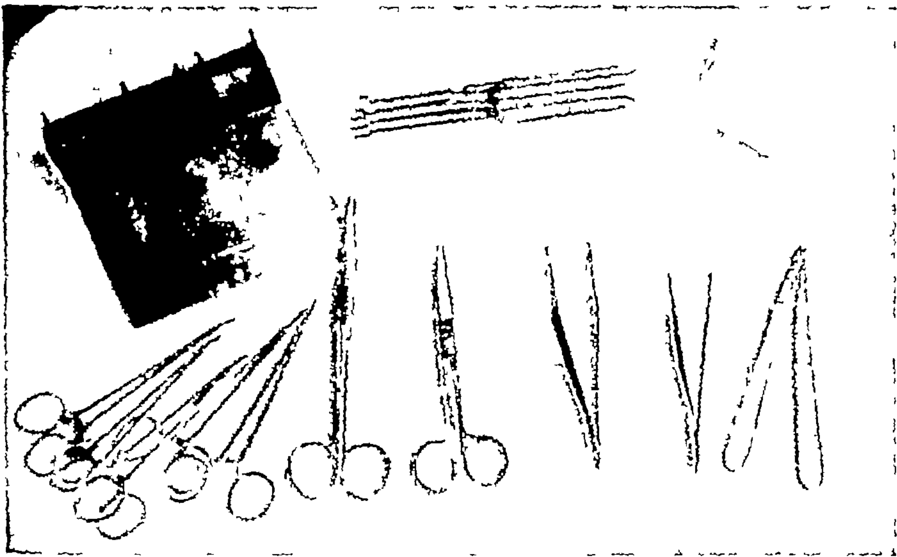


FIG 14—Small instruments used for hand surgery Note mosquito hemostats, curved scissors with sharp and blunt points, fine thumb forceps, small-sized knives, small, sharp retractors and fine wire

should be nonirritating and should not cause strangulation of tissue Catgut is absorbed in an irregular manner and is always irritating Silk and cotton are less irritating than catgut and are not absorbed, but they may act as foreign bodies and, should infection occur, will interfere with wound healing Size for size, wire is stronger than other materials and is less irritating, but it is more difficult to handle and sometimes has to be removed afterward

Sizes—To control bleeding in the hand, the ligature should be applied directly around the vessel, after picking the vessel up with a mosquito hemostat and drawing it out from the surrounding fat If this is done, the ligation is made with 4–0 or 5–0 plain catgut, 4–0 or 5–0

or by the surgeon who uses it often enough to master the technic There is some risk, and unless the technic is accurately carried out anesthesia is incomplete and inadequate A certain number of patients have residual neuritic phenomena, and hematomas due to injuries to the vessels are not uncommon

General Anesthesia

With newer adjuncts to general anesthesia—Pentothal induction, re-breathing with a gas mask and curare for muscle relaxation—a patient may be comfortably and safely carried through a long period of anesthesia without any ill effects When general anesthesia is to be prolonged, it is fairly routine to administer appropriate fluids, such as glucose and saline, intravenously Blood is rarely needed unless a great deal has been lost before operation

Curare relaxes skeletal muscle, making tendon repairs easier Curare is not recommended unless it is administered by a trained anesthesiologist or by a nurse thoroughly familiar with its use It is definitely contraindicated in shock and may be contraindicated in cardiac states

SURGICAL TECHNIC

The repair of hand injuries is a combination of bone and soft tissue surgery It is not intended in this text to present any complicated apparatus or procedures, the equipment available in the ordinary hospital being adequate The instruments and general technic to be outlined are given to enable the operator to do simple surgical procedures on the hand more efficiently

INSTRUMENTS —Instruments should be small and delicate (Fig 14) Properly used, mosquito hemostats are large enough for any vessel encountered. A few larger hemostats are useful to make traction on the ends of tendons, however, when they are used, the crushed tissue must be cut away afterward Two-pronged, sharp tracheal hooks are the most convenient retractors Sharp-pointed scissors, curved on the flat, will be found to be very efficient after the operator gets used to them A small blade scalpel is much handier than the usual size Small needle holders, such as Brown's plastic ones, do not break or flatten the small, curved needles Several sizes of small thumb forceps should be available, including the finest possible three-toothed pincette for handling nerves The tendon strippers and tendon-passing probes devised by Bunnell are not necessary in repairs of fresh injuries but will be needed for secondary repairs *

*Robert Larsen of Detroit has designed a tendon-holding forceps which sounds promising.

Drapes—The proper draping is shown in Figures 15 and 16 A folded blanket is placed over the armboard and a triple thickness of sterile linen incorporating one layer of waterproof fabric is put over this An apron type of towel drape is fastened around the arm just below the blood pressure cuff A length of sterile stockinette is drawn over the arm to the apron, and sterile finger cots are used on the fingers Additional linen placed over the upper arm covers the apron and the patient's chest, long

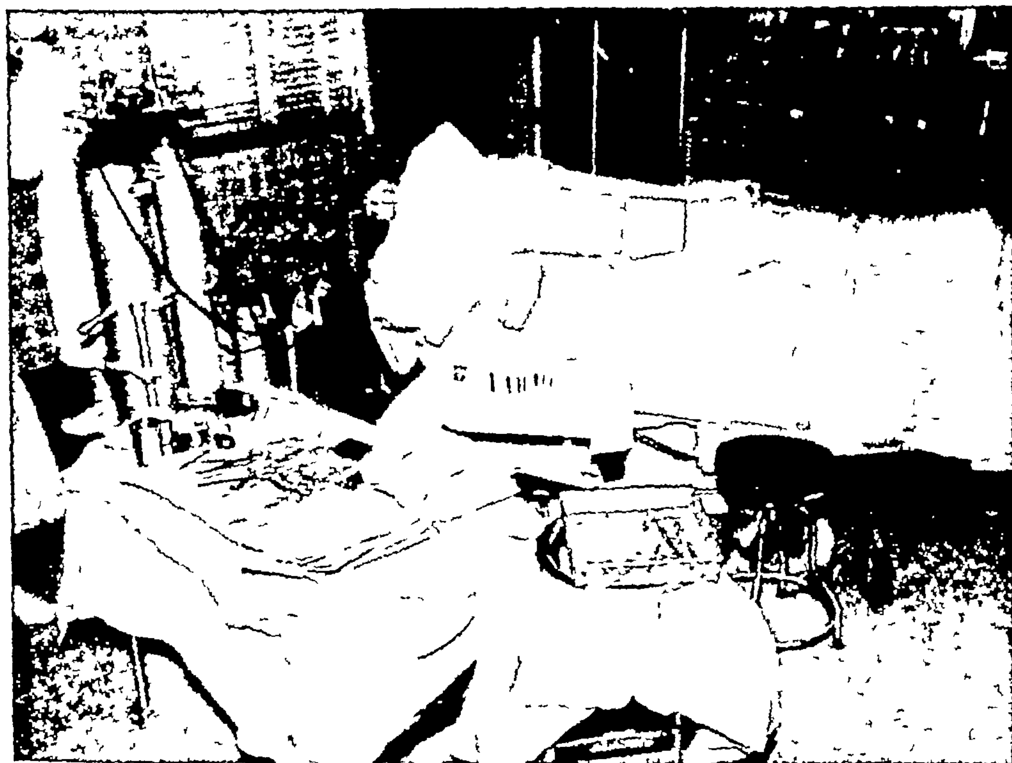


FIG 15—Complete surgical setup Drapes isolate injured extremity and donor area for bone graft Anesthetist is screened off Forearm is covered with stockinette, finger cots should be used to cover patient's nails

linen covers the body and legs, and the usual linen screen cover is used to avoid contamination from the patient's breathing

A suitable armboard is about 6 ft long, 1 ft wide and 1 in thick It supports both arms and is very stable The uninjured arm is kept out on the other end of the board for intravenous administration of fluids as indicated.

SURGICAL ROUTINE—The surgeon should keep in mind that he is dealing with structures which have already been injured, which are contaminated and which may be at the borderline of viability It follows that no tissue should be seized by crushing clamps unless it is to be later

silk, no 60 cotton or 38 gauge steel wire In sewing the skin together, no 36 or 38 wire is strong enough, or 3–0 silk or no. 40 cotton may be used Apposition, not strangulation, makes wounds heal In repairing tendons, if silk or cotton is used it should be strong enough to stand a 3–5 lb pull For tendons, no 34 or 36 stainless steel wire or a twisted multiple-strand steel wire (Fagersta 005 × 3 or 003 × 5) is usually strong enough For internal fixation of bones, no 20 stainless steel wire or a slightly smaller size is used The absence of capillarity and irritation with monofilament sutures, especially wire, makes this material particularly desirable in hand repairs All suture material, including wire, loses some of its tensile strength with repeated sterilization Older material should therefore be discarded

TOURNIQUETS—Improved pneumatic tourniquets are constantly being devised The latest model works on canned gas and has an automatic, preset pressure regulator This devise is a luxury, but it is relatively foolproof if the pressure gauge is kept in plain view If a pneumatic tourniquet is not available, an ordinary aneroid sphygmomanometer with a new rubber bladder is suitable Whichever type is used, the tourniquet should be carefully applied to avoid creasing the skin and should be inflated to about 300 mm of mercury for an adult and 200 mm for an infant The ordinary blood pressure cuff is held in place by wrapping an Ace bandage around it No blood pressure cuff should be left on more than an hour and a half Before the cuff is pumped up the arm is rendered bloodless by elevating it and wrapping it from the finger tips to above the elbow with a sterilized Esmarch or 3 in Ace bandage The cuff is inflated as rapidly as possible and the bandage is then removed

PREPARATION OF OPERATIVE FIELD—Before the drapes are applied, the wound is covered with sterile dressings and the rest of the hand, the forearm and upper arm are scrubbed with soap and water until clean Some of the newer scrub-up preparations containing hexachlorophene may be used instead of soap The area should then be shaved and painted with some colored antiseptic The color assists the surgeon in seeing the extent of the sterile field Mechanical cleansing of the skin is the keynote to good asepsis

It is usually best to anesthetize the patient before the wound is cleansed The initial part of wound cleansing can be done directly after the skin is prepared Copious quantities of sterile saline are poured into the wound Dirt, blood clots and detached fragments of tissue are washed and gently sponged away, using sterile technic The drapes may then be applied and the surgeon finishes converting the contaminated area into a clean wound

operations on specific tissues are described in their appropriate sections However, there are a number of circumstances under which these incisions are used for other operations For the reader's convenience most of the ordinary problems are discussed here

Whenever a lesion on the hand requires excision the surgeon must be prepared to close the wound with a skin graft, because even small deficiencies of skin, especially on the palm and fingers, can result in disability from tightness If such an excision requires a skin graft in an undesirable location, primary graft should be by a local rotation flap that will place the secondary donor area in a location where a split thickness graft will give an adequate result Some of these problems are discussed in Chapter 7 The reader is also referred to texts on plastic surgery The incisions described in the following paragraphs are all simple incisions that do not require grafts

Surgical incisions in the hand should take advantage of lines where the skin does not move (to avoid contracture), should be planned so that kindly healing will occur and should give the required exposure A midlateral incision in a digit corresponds to the midline incision in the abdomen It gives good exposure, can be extended and in healing does not interfere with function An incision along a crease in the palm does not jeopardize blood supply to the flap and heals without contracture Midlateral incisions in the palm are occasionally useful but do not give good exposure unless they are used as extensions of palmar crease incisions Whenever an incision crosses a joint on moving skin, a zigzag should be made to reduce scar contracture Palmar skin, with its specialized whorls and padding and abundant pacinian corpuscles, should not be sacrificed unnecessarily, any replacement is inferior to palmar skin

In operations on the hand and forearm it is often advantageous to dissect the skin away from the deep fascia before proceeding with surgery The flaps thus created are well supplied with arteries and veins, perforating vessels are ligated at this level, and cutaneous nerves that penetrate the deep fascia and lie beneath it and the skin can be protected Surgical attacks on the deep structures of the hand invariably require opening the deep fascia Where this fascia is thin and acts only as an enveloping membrane, as on the forearm and dorsum of the hand, it may be split or, if scarred, excised, generally it can be ignored in wound closure Small holes in deep fascia give rise to muscle hernias, which are corrected by enlarging the holes

When a tendon-supporting ligament (transverse or dorsal carpal ligament) is incised for exposure it is best to detach it laterally from one of

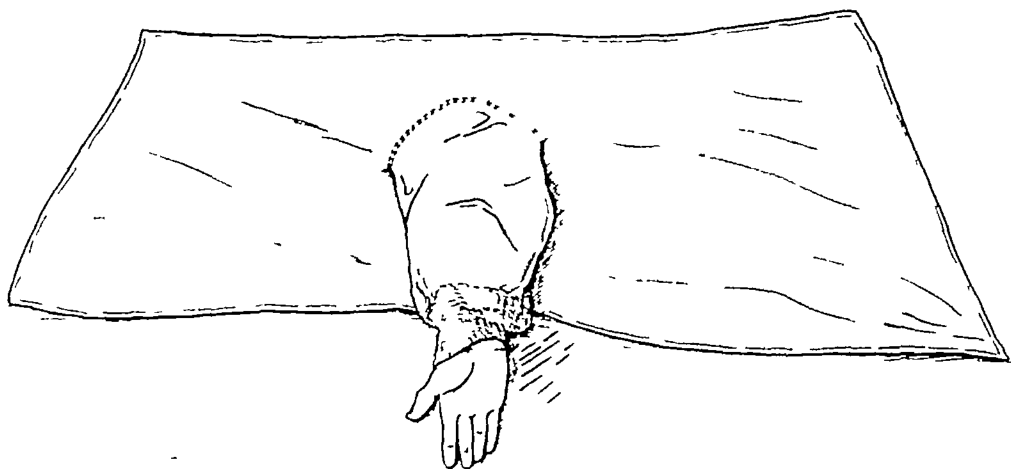


FIG 16—One-piece sleeve drape which simplifies sterile technic in the operating room

removed, and every effort should be made to avoid inflicting additional trauma by rough handling The wound edges should be drawn back with retractors rather than thumb forceps Forcible retraction should be circumvented by the use of proper incisions, which should be placed so as not to impair the circulation of flaps The tissues must be kept constantly moist with saline and not allowed to dry out from the heat of surgical lamps Additional contamination caused by unmasked personnel in the operating room should be avoided The operation must be conducted along the lines of ascertaining the amount of damage, making minute debridement, repairing those structures which are certain to heal, and avoiding attempts to do the impossible or steps which might make the original injury worse

Debridement—The term debridement has several connotations It is used here to mean the picking out of every bit of foreign material and devitalized tissue from a wound It implies the necessary visualization of all the crannies of the wound, with retraction of the edges and whatever incisions are necessary to carry out this process Wound excision in the hand is impractical, but dead tissue must be removed Tissue too badly damaged to survive, muscles squeezed out by rollers, and subcutaneous fat, which is often avascular without apparent change, must also be removed Whenever wounds are enlarged for access to the deep structures, the incisions should be along physiologic lines, preferably from the ends of the traumatic opening Further discussion of these problems will be found in chapters on specific injuries

INCISIONS—In any operation on the hand the surgeon must make an incision that will not interfere with function later Most incisions for

necessarily varies from case to case, and an exact description of it is difficult It combines wide exposure with minimum wound complications or postoperative contractures It is not suitable for tendon or nerve repairs and should not be used for them

A long incision for exposure of the median nerve and/or tendons in the palm, carpal canal and forearm regions can be made by incising along the thenar crease, turning somewhat radially at the base of the thumb, then curving toward the ulnar side of the wrist to connect with a serpentine in the forearm (Fig 17, *B*) The transverse carpal ligament should be incised so that the skin incision does not correspond with the ligamentary incision This incision gives excellent exposure to all the tendons and the median nerve here and is designed to protect the tendons during healing The palmar portion of this incision lies directly over the tendons to the index finger and with a little undermining gives good exposure to the tendons of the long finger For exposure of the tendons of the ring and little fingers in the palm an incision is made along a faint crease line along the fourth cleft

Incisions in the distal palm should be transverse, either parelleling or lying in the lines of the flexion creases In operations on the fingers and thumb, midlateral incisions give the best approach to flexor tendons and nerves A short transverse incision may be used for excision of small ganglia or other small tumors In any transverse incision in the digits, the digital nerves should be protected At times the surgeon will want to expose the structures in the thenar eminence By making a long incision midlaterally over the proximal phalanx and metacarpal of the thumb, a flap of skin and subcutaneous tissue can be turned up and the entire thenar musculature, together with nerves and tendons, will be exposed This incision is quite satisfactory for nerve or tendon repairs and if careful attention is paid to hemostasis kindly healing is assured

The motor branch of the median nerve should be carefully protected in any operation on the palm of the hand or carpal tunnel I prefer always to dissect it out and identify it when doing a palmar fasciotomy for Dupuytren's contracture, since it has often been damaged in this operation When the motor branch of the ulnar nerve is damaged in a deep saw cut or in a puncture wound of the ulnar side of the hand, it can be dissected out and repaired through an incision along the proximal transverse palmar crease, turning down the ulnar border of the palm at the metacarpal level (Fig 17, *C*) The skin and subcutaneous tissues are raised as a flap and turned back to completely expose the origin of the hypothenar muscles from the hook of the hamate and the origin of the

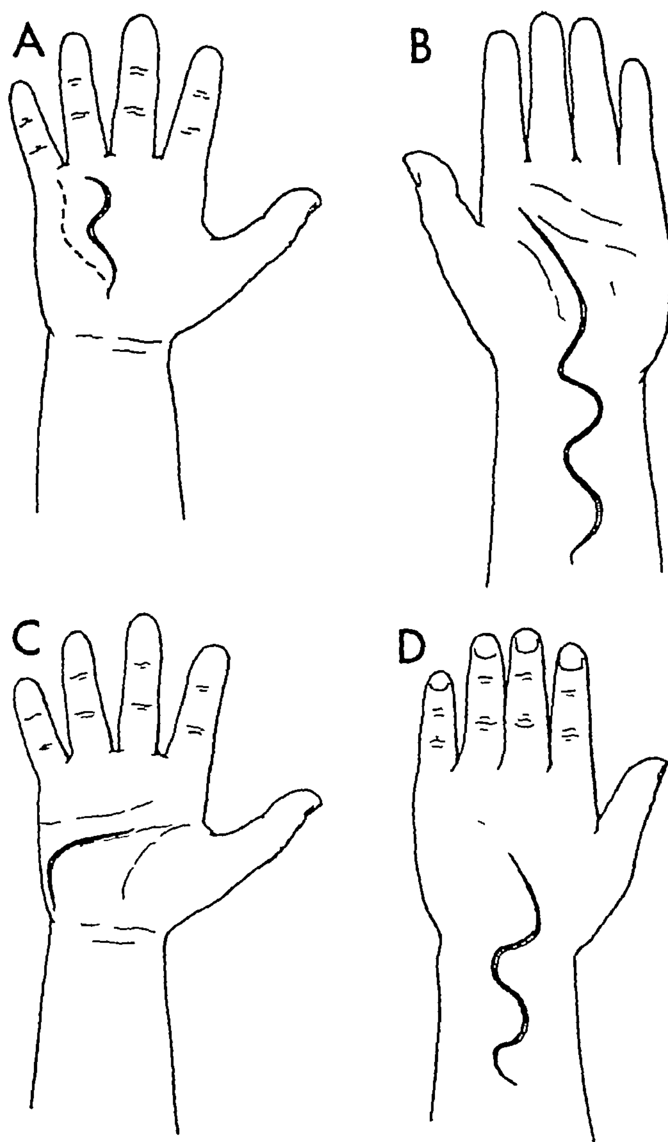


FIG 17 —Incisions (see text for description)

its bony insertions In this maneuver the incisions should be staggered so that the fascial incision will lie under an intact flap of skin instead of under the skin incision In many operations in the palm, a partial palmar fasciectomy will give better exposure to the nerves and tendons beneath and will allow the healing tendons to lie against the more mobile skin

Palmar incisions—The most extensive incision commonly used to uncover the palm is made in the operation for Dupuytren's contracture (Fig 17, *A*) I prefer a linear serpentine incision that follows natural creases in the palm over the area of maximum pathology This incision

more extensive wounds, too much wrapped around the extremity may give too tight a dressing

For multiple wounds, each wound is covered separately with grease gauze followed by dry gauze sponges but no circular gauze The fingers are separated by strips of dry gauze and the entire forearm and hand then wrapped with sterile compression cotton about 2 in thick Compression is achieved with a spiral bandage applied over the compression cotton and extending from the upper forearm to the finger tips Positioning of the extremity is effected before the dressing is applied to prevent the dressing from creasing the wrist or becoming too tight or too loose After the compression dressings are in place, plaster splints are applied, followed by further bandaging In the chapters on specific injuries the correct splinting for each will be described This splinting should never be omitted

The extremity is kept elevated on pillows or an armboard or in a sling (Fig 18) for at least 48 hours postoperatively, after which the patient is instructed to hold the hand above the heart level when he is ambulatory and to keep it propped up when he is sitting or lying down

Absence of pain is an indication that all is well in the wound If much pain is present, circulatory embarrassment or infection should be looked for In either case, the dressing should be inspected Sometimes a minor change in position is all that is required Again, it may be necessary to remove sutures rather than to jeopardize the part by loss of circulation

The amount of motion permitted depends on the injury Involuntary motion at the finger tips will not interfere with the healing of nerves and tendons and may be permitted if it does not interfere with the suture line in the skin The uninjured parts should always be exercised daily

Drug therapy —The therapeutic armamentarium is perpetually changing, so that whatever antibiotic and chemotherapeutic agents are good today may be archaic tomorrow Of these substances, the best available should be given in therapeutic doses but these agents should never be used to take the place of adequate surgery In the more complicated cases antibiotics are usually helpful, in simple, clean lacerations they are of questionable value In addition, 250 mg of vitamin C is given three times daily by mouth

Suture removal —On the palm of the hand and the anterior surface of the fingers some sutures should remain for 10 days, but on the back of the hand and forearm somewhat earlier removal is permissible One advantage of wire sutures is that they may be left in for a considerable period without causing irritation End-on mattress sutures bury themselves, these are conveniently removed on the fifth day

deep and superficial branches of the ulnar nerve The muscle origins are detached and the nerve can then be followed down into the depth of the palm

Dorsal incisions—Dorsal incisions on the hand may be linear, transverse or serpentine (Fig 17, *D*), depending on the operator's preference and the exposure required A jog is made in the incision wherever a joint is passed, and sharp corners are avoided The result is a variant of the serpentine or Z, which prevents contracture In the forearm a midlateral incision is perfectly safe, but a long volar or dorsal midline incision is apt to cause keloid formation This can be avoided by using the serpentine principle

The wrist extensors and brachioradialis are the first muscle bellies encountered at the external epicondyle In operations on the head of the radius one will encounter these muscle bellies as well as the underlying supinator muscles and the motor branch of the radial nerve, which passes through the supinator and supplies the extensor muscles The main muscular branches to the extensor muscles are given off somewhat distal to the supinator In approaches to the upper end of the shaft of the radius these branches can be picked up between the deep and superficial groups of muscles

POSTOPERATIVE CARE

Postoperative care starts as soon as the operation is completed and ends when the hand is being used as normally as possible Injured tissues need rest With splinting, the wound heals more quickly than with too early motion Splinting, however, will encourage stiffness, and to minimize this the uninjured parts should be moved Swelling, which deposits protein materials, is followed by scarring and loss of mobility Rest, elevation and gentle compression are the three important factors in the prevention of swelling, delayed wound healing and stiffening

DRESSING OF WOUNDS—The wound should be dressed by placing a single thickness of petrolatum gauze directly over the wound and covering this with a gauze sponge which is laid out flat, without creases Hematomas are the bane of hand surgery Compression and drainage are often indicated in extensive wounds For compression, various materials are available and, in one way or another, each has advantages and disadvantages Kerlix, an elastic form of gauze bandage, is quite useful about fingers and hands to give mild compression without strangulation Tube gauze or Surgitube properly applied to fingers will provide mild compression and splinting These are easily sterilized and simple to apply In

PHYSICAL THERAPY—The best physical therapy for the hand is that which the patient gives himself, intelligently supervised by the physician The general principle back of all physical therapy of the hand is *use.* When a workman injures his foot he quickly learns either to walk on it or to stay off of it and keep it elevated Unfortunately a less satisfactory situation occurs with the hand By substitution, the other hand is used for most everything, not being used, the injured hand hangs down and swells. Because the hand is stiff and painful when an attempt is made to use it, a vicious cycle develops with more stiffening, more pain and less use

After the splints and dressings are off the patient should be encouraged to *exercise the hand* Some patients show a remarkable susceptibility to

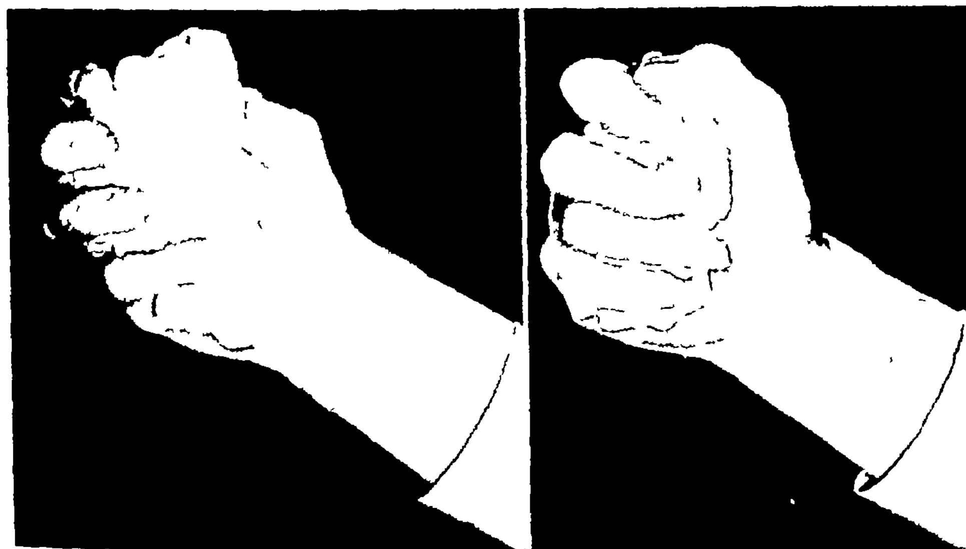


FIG 19—Exercising finger joints by squeezing handkerchief

stiffening, these patients also complain of pain and need encouragement They should be told that the pain suffered from movement does no harm and that if they persevere in exercising the pain and stiffening will disappear Every possible means should be employed to make the patient use the hand as normally as possible Trick movements and substitution movements should be prevented These become habitual and lead to stiffening and considerable disability

Physical therapy will aid in overcoming stiffening and pain Heat and massage help to relieve the swelling and pain Passive movements do not usually improve stiffness, but active movements do Active exercises against resistance are best, squeezing a pocket handkerchief or rubber sponge (Fig 19), wadding up a piece of newspaper on a table, wringing

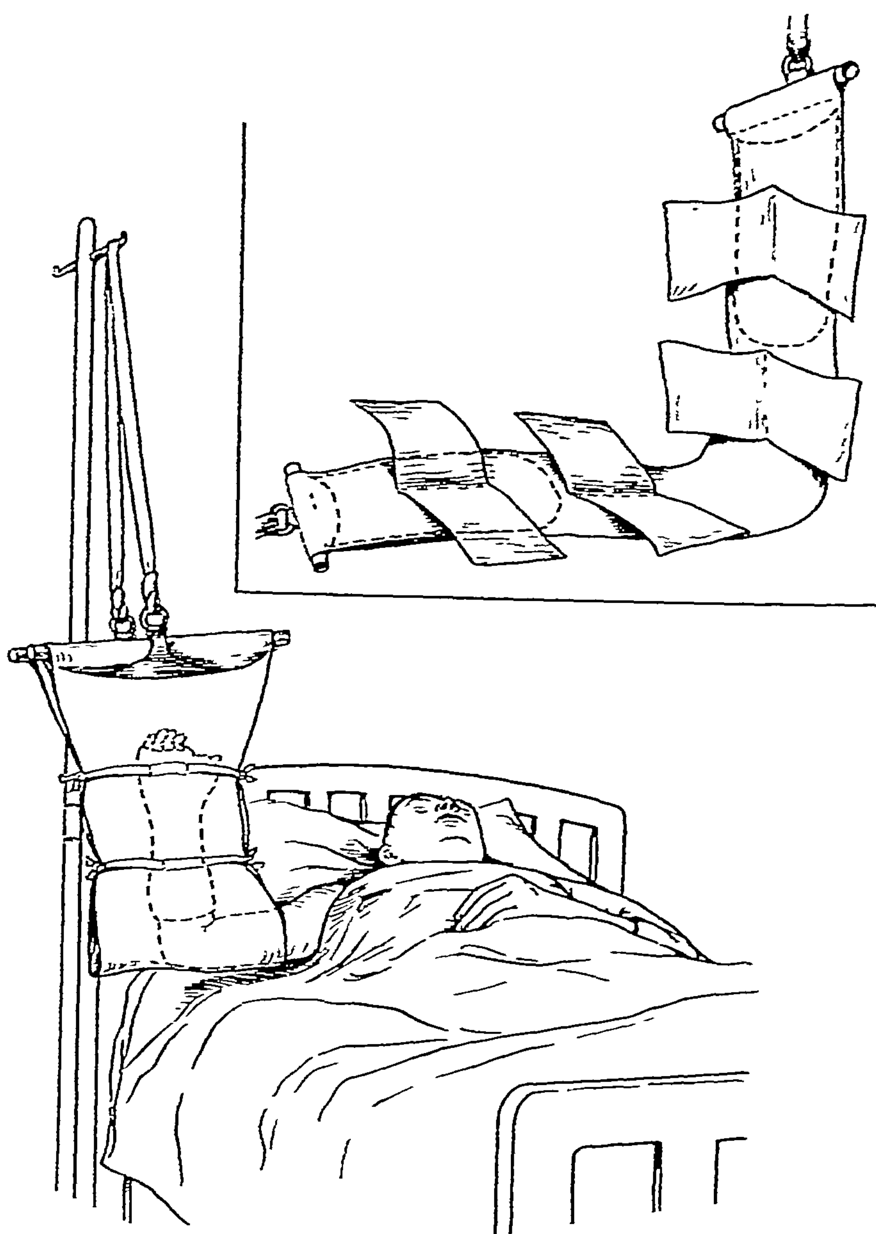


FIG 18 —Sling for postoperative care of hand cases. Pain is reduced and healing aided by splinting, elevation and mild refrigeration with ice bags. In cases with much oozing of blood, continuous suction with Gomeo unit is applied to small perforated catheter drains

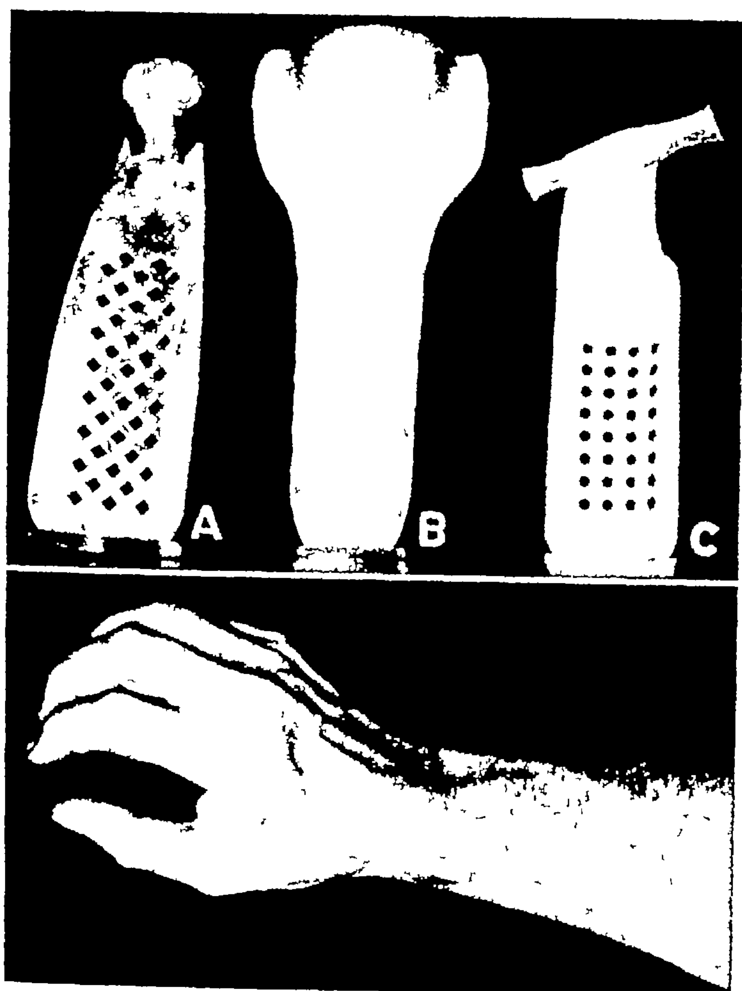


FIG 21 *(above)* —Wrist splints *A*, cock-up splint, *B*, Mason-Allen position-of-function splint, *C*, Colles' splint, now rarely used

FIG 22 *(below)* —Position of function

is immobilized in a flexed position and can be twisted to fit the thumb It is usually adequate for undisplaced fractures of the proximal and middle segments of the finger and should also be applied after reduction of dislocations of the finger joints and after repair of lacerations which cross flexion creases It usually is inadequate to maintain the position of a displaced fracture after reduction

An aluminum splint for treatment of fresh mallet-finger injuries has an aluminum band which passes around the proximal and middle segments of a finger and a projection which holds the tip of the finger up This splint requires more skill in application and does not hold the finger as well as a small plaster cast

out cloths in hot water and squeezing a small square block, which may be carried in a pocket, to flex the interphalangeal joints are all useful methods Contrast baths, in which the extremity is immersed in hot and cold water alternately for two or three minutes at a time, aids the vasomotor system in returning to normal Whirlpool baths supply gentle massage and heat These can be used even before healing is complete When available, paraffin baths and warm sand baths in which active exercises are carried out may also be useful

Nothing is so good for the hand as the man's returning to his work as a mechanic, carpenter, etc, which requires use of the hand. During the first few weeks he may have considerable pain, but if he can endure this period and uses *all* the hand properly, the outlook is good

SPLINTING

Most splints used in the treatment of acute injuries are found in the average hospital or can be improvised, using either plaster, wood or wire Standard aluminum splints are also available (Fig. 20). The four-pronged finger guard is useful in any nail injury, in fracture or contusion of the distal segment and sometimes in a laceration of the middle segment The aluminum gutter splint which immobilizes the metacarpophalangeal joint as well as the other joints of the finger is much better than the old-fashioned tongue-blade splint This splint may be bent so that the finger

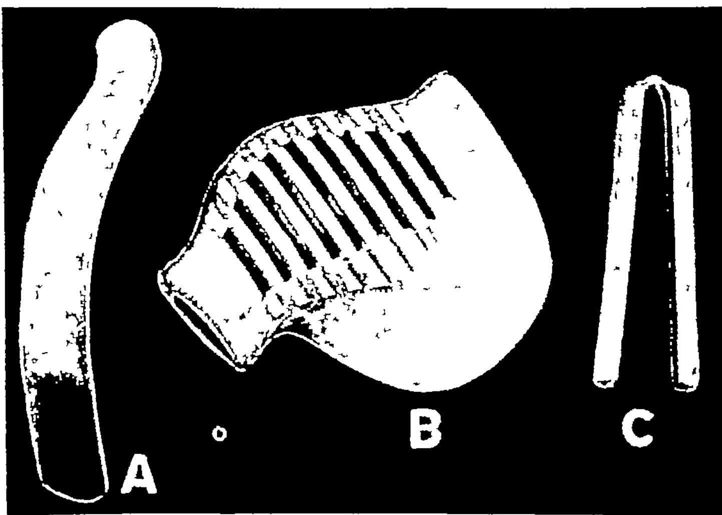


FIG 20—Small hand splints *A,* aluminum gutter splint, *B,* metacarpal bar, sometimes used in immobilizing hand in boxing position, *C,* four-pronged finger guard

loosen the hand between reconstructive procedures but are rarely indicated in the care of acute injuries

Plaster of paris is the best splint for any kind of fracture Although not generally used in fractures of the fingers, it is the ideal dressing for the fresh mallet-finger injury It is also used for simple wrist injuries

For fractures requiring traction, a cast is applied to the forearm with the wrist extended about 15 degrees First, a thin layer of sheet wadding is applied to the forearm, wrist and metacarpals, wet plaster splints are laid on in the volar and dorsal surfaces, fitting them to the contours, and gauze or plaster bandages are used to hold the splints in place, avoiding constriction The half-dry plaster is then trimmed to the transverse palmar crease and cut away around the thumb (Fig 24) Unpadded casts



FIG 24 —Simple cock-up cast trimmed to allow fingers and thumb full motion

are difficult to apply without causing pressure sores A bulky cast is to be avoided The cast should never be bent or creased after it is applied and the traction device should not be attached until the plaster is fairly dry

It is exceedingly important to avoid having the cast too tight, since *Volkmann's contracture* has resulted from prolonged compression of the forearm The exact pathogenesis of this condition is still *sub judice;* the changes in experimentally produced ischemic necrosis are not identical Cases with involvement of one particular set of muscles tend to substantiate the vascular origin of the disease In my experience, many cases of crush injury end with a fibrosis and contracture of the musculature which is more or less similar to the end picture of Volkmann's contracture, even when no cast is used Use of a tight cast in crush injuries is therefore doubly dangerous After any splint or cast is applied, the finger tips should be exposed so that they can be inspected, and if pain, cyanosis or

To immobilize the wrist the splint should extend to within 1–2 in of the elbow for comfort For most simple wounds as well as for sprains, burns, etc, the hand should be immobilized in a position of function, that is, with the wrist cocked up, the fingers spread slightly and flexed a little at each joint and the thumb in a position of abduction The thumb should never be immobilized hugging the palm, because a contracture will result The simplest splint to keep the position of function is a board, on one end of which a pile of gauze is built up to elevate the palm

Of the many aluminum splints for the wrist (Fig 21), the simplest is one with the end turned up to support the palm, the fingers being free This type is suitable for use in wounds on the back of the wrist, as a con-

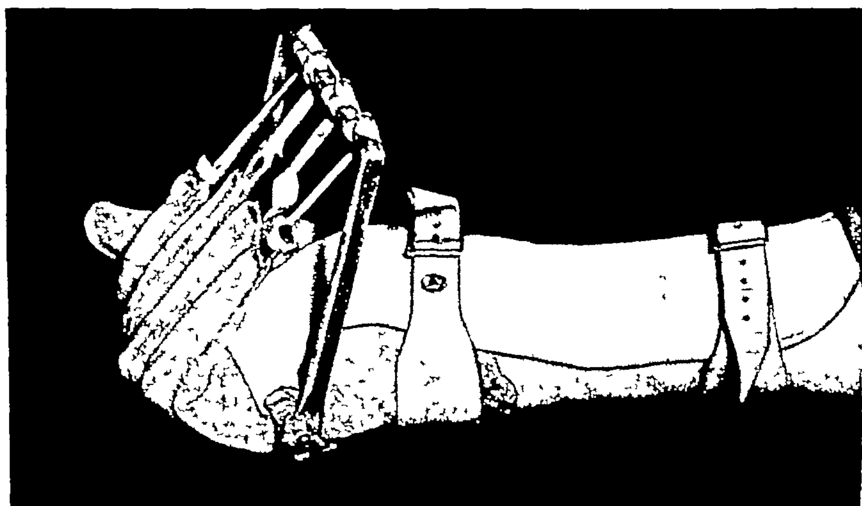


FIG 23 —Splint to mobilize stiff finger joints

valescent splint or to immobilize sprains of the wrist, etc Another type of wrist and forearm splint is the Colles' fracture splint which has a cross bar for the metacarpals to rest on This splint may be bent to hold the wrist up and may be incorporated inside wet dressings in hand infections

Regardless of what method is used to immobilize the hand, the position of function (Fig 22) should always be kept in mind The finger should never be splinted straight out and the wrist should not be flexed unless there is a definite indication, such as a severed flexor tendon The principal advantage of aluminum splints is that they can be easily removed and reapplied, permitting dressings to be changed or the hand to be washed

Bunnell has devised an ingenious and complete set of splints for active splinting of the hand Traction splints (Fig 23) are often needed to

loosen the hand between reconstructive procedures but are rarely indicated in the care of acute injuries

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loss of sensation develops, the dressing should be removed immediately Swelling is further avoided by keeping the extremity elevated

Plaster of paris is made of anhydrous calcium sulfate * The setting time is determined by various activators mixed with the plaster. Commercially made bandages, though slightly more expensive, are of uniform quality and are ideally suited for forearm and hand casts The bandages are soaked in water, the saturation point being indicated by the disappearance of bubbles in two or three minutes, and are then grasped at the ends with both hands and excess water expressed by pushing the hands together and making a slight twisting motion Either sheet wadding or plaster of paris bandages should be applied so that each turn overlaps the previous turn about one-half Bandages and splints should be applied without interruption to make the cast uniform Construction at any one point must be scrupulously avoided As the plaster is applied, it should be rubbed in a little with each turn around the extremity No rubbing should be done after the cast starts to set Until it has set, the cast should have no weight on it, otherwise denting will occur *If any large amount of swelling is anticipated, the cast should be split from end to end*

* Plaster combined with a resin (Melmac) is available This is stronger and nonwettable after setting but occasionally causes dermatitis

CHAPTER THREE

Minor Injuries; Arterial and Joint Injuries

MINOR INJURIES

THE DIVISION between minor injuries and major injuries in hand surgery is really without meaning In hand injuries the treatment carried out, whether definitive or emergency, is often the deciding factor A laceration of the palm with severed nerves and tendons may be treated as a simple laceration, in which instance it would be classified as a minor repair, whereas if early definitive treatment were carried out it would certainly be a major undertaking Similarly, a minor wound involving a joint may become a major problem if infection which cripples the hand results from improper original treatment In many major injuries of the extremity there are associated minor injuries of some of the digits, such as torn nail beds, open wounds of the joint or abrasions, which also require attention These miscellaneous conditions, which may occur alone or in combination with more complicated wounds, are considered in this chapter

LACERATIONS

The simpler wounds of the hand involve the skin only, and in properly caring for them certain steps should be routine First, the hand should be carefully examined to make sure there are no complications, such as injuries to nerves, tendons or bones The origin of the wound should be determined as well as the type of first aid treatment given Whereas a clean wound sustained in the house does not require that treatment for tetanus be given, one received in a street or barnyard accident does. Frequently first aid treatment has added contamination to the wound

Appropriate antibiotic substances, tetanus antitoxin and other specific therapeutic measures should be given according to the indications

The ordinary emergency room or office setup is perfectly satisfactory to repair minor lacerations provided the principles of asepsis are followed Sterile operating room technic should be used Local anesthesia is usually appropriate, the agent being injected through the intact, sterilized skin. The wound then is cleansed and blood clots, foreign bodies and devitalized tissue removed Ligation of bleeding vessels is necessary but use of excess catgut or buried nonabsorbable suture material should be avoided In suturing, a fine nonirritating suture material is used and each stitch is made just tight enough to bring the skin edges together without strangulating Better results will be obtained with an everting type of suture such as the end-on mattress suture In the initial dressings a single layer of petrolatum gauze next to the suture line makes redressings easier.

Immobilization in the position of function should be maintained with gentle, firm compression surrounding all immobilized areas The patient should be instructed to keep the hand elevated, to keep it clean and dry and to report to the physician if any untoward symptoms develop

Contusions and Hematomas

Contusions of the fingers and hand vary in severity from simple bruises to complicated crush injuries The common factor in all is the effusion of lymph into the injured area, producing swelling and limitation of movement The effusion is later replaced by fibrous tissue which infiltrates the tissue spaces In the early months and especially in young persons this fibrosis may resolve, but after six months and in older individuals it becomes permanent This is the frozen hand. Diagnosis is important Partial crushing of the rest of the hand is usually overlooked when one finger is mangled, as in an industrial press or auto accident

For successful treatment, the physician must be on the alert to detect contusions and to prevent swelling Immediate rest, elevation, compression and splinting in the position of function for 48 hours will save many weeks of physical therapy later X-rays should be taken to rule out fractures

The practice of treating contusions by immediate use of hot soaks is mentioned chiefly to be condemned During the early period ice packs are better, with the physiologic rest of elevation and compression

After the splints are removed the patient is encouraged to exercise the hand as much as possible, moving each joint and using the whole hand normally. Physical therapy may then be an aid Cortisone therapy has

been suggested in treatment It should be recalled that cortisone inhibits wound healing and is conducive to infection Case reports of disastrous results following administration of cortisone therapy have appeared.

Closely related to contusions, hematomas of the hand usually result from crushing injuries, severe blows, avulsions without complete separation of the skin, puncture wounds and occasionally some seemingly trivial injury A hematoma of the distal closed space of the finger is fairly common and may be mistaken for a felon (Fig 25)

Most hematomas will be found to react favorably to early refrigeration followed by heat and occasional aspirations Under some circumstances, a condition known as hard dorsal edema develops in a hand which has



FIG 25—Hematoma of distal closed space caused by catching finger in car door Refrigeration for 24 hours followed by heat gave good result

had a known hematoma This is characterized by swelling and stiffness, especially around the metacarpophalangeal joints, and a hard edema which does not pit on pressure and is limited to the back of the hand, not involving the wrist and fingers Microscopically, the involved tissues show fibrosis and sometimes the formation of false bursae The condition is a chronic inflammatory one, and unquestionably extravasation of blood is a causative factor Excision of the fibrous tissue does not always result in a cure Physical therapy is likely to have little effect Sympathectomy has been used, and immobilization in a plaster cast has its advocates. Evacuation of the hematoma would appear to be profitable when it can be carried out, obviously, when the blood is extravasated into the tissues and becomes diffused evacuation is not feasible

Abrasions

Abrasions of the hand are somewhat like burns in that there is a partial loss of epidermis together with contamination of the area and, at times, avulsion of whole thicknesses of skin If only a partial thickness of skin is missing, the area should be washed, under anesthesia if necessary, to remove all dirt and a bland ointment applied with adequate dressings to immobilize the area If no infection occurs, the dressings are left on for a week to 10 days, when removed, the area should be healed When part of the skin is avulsed and is hanging, this should be cleansed and



Fig 26—Soft tissue defect of finger closed by immediate skin graft. *A,* original injury, *B,* result

sutured back into place (see Chapter 7) When there is a defect of the skin, replacement should be made with a skin graft (Fig 26)

Puncture Wounds

The principal danger in puncture wounds of the hand is infection Particularly, any puncture wound which enters the tendon sheath or joint should be regarded with wholesome respect The affected digit or joint should be immobilized by a splint, antibiotics given and the patient kept under close observation When a known virulent organism is present in the contaminant, the patient should be hospitalized and wet packs used in addition to antibiotic therapy If a puncture wound is contaminated by spore-forming organisms, tetanus antitoxin should also be given Most of these injuries will respond well to early prophylactic treatment, and if no infection has developed within 48 hours normal activities may be resumed

HUMAN BITES

It is generally considered inadvisable to suture these wounds They should be thoroughly cleansed with soap and water or Zephiran, and limited debridement performed, after debridement saline irrigation is desirable Preferably, the patient should be hospitalized for observation and moist packs applied to the wound Tetanus antitoxin is not necessary Cases seen late usually require incision and drainage, together with appropriate antibiotics

FOREIGN BODIES

The finding of foreign bodies in the hand is an everyday occurrence, the most common being wood slivers, metal chips or pieces of needles, bits of glass, fish hooks, thorns, bits of wire or even lead pencil points In many cases there are no symptoms, the patient presenting himself with a minute wound and the story that a foreign body has entered the hand Diagnosis in the case of a metallic foreign body or piece of leaded glass is confirmed by x-ray. The location of a foreign body can, at times, be suspected by the symptoms produced as well as by the wound of entry and speed of the object Irritating foreign bodies, such as pieces of wood or thorns, quickly give rise to an inflammatory reaction and within two or three days an abscess is often produced Nonirritating foreign bodies, such as bits of metal or glass, may cause symptoms when they lodge within nerves or tendon sheaths Figure 27 shows a broken needle within the ulnar nerve in the carpal region In this patient a shocklike phenomenon was produced when this area was percussed or when the fourth and fifth fingers were extended If a foreign body lodges within a tendon sheath, some crepitation and limitation of motion may result

The treatment for all foreign bodies in the hand is removal, however, nonirritating foreign bodies which are doing no harm and which are lodged in the depths of the hand where removal would be difficult may be left alone In routine x-rays of a workingman's hands it is not at all uncommon to see several pieces of steel which the man does not know are there Bird shot which apparently caused no difficulty have been observed in hands However, any foreign body which lies in a tendon sheath or in a nerve should be removed Movement demonstrated by x-ray confirms the diagnosis of a foreign body in a tendon sheath In a nerve, symptoms of nerve irritation occur Foreign bodies should be removed from joints and from the vicinity of vessels without waiting for complications to appear If a foreign body traverses a large vessel, damaging it,

an aneurysm may result, this is easier to repair after the primary wound is substantially healed Fortunately, collateral circulation in the hand is so abundant that the problem of ligating a vessel rarely causes any circulatory insufficiency

Perhaps the most difficult foreign body to locate is a small piece of glass which is not radiopaque In such instances, it is often easier to allow the primary wound to heal and then as an elective procedure to re-explore the area in a bloodless field A wooden foreign body or any irritating





FIG 27 *(left)* —Foreign body (needle) in ulnar nerve
FIG 28 *(right)* —Piece of wood (measuring 3 5 × 0 5 cm) which had remained in thenar space eight years Median nerve neuritis then developed, relieved by removal of the foreign body

object should always be removed as soon as circumstances permit Large ones can frequently be palpated running for considerable distances through the hand (Fig 28) Sometimes a piece of wood is broken off so that it is more accessible from an incision made where it might emerge than from the original wound of entry Care should be taken to remove all the smaller pieces of wood This procedure can often be done in the office but may require major operating room facilities

Removal of foreign bodies with the aid of the fluoroscope is now universally condemned because the skin and tendons on the back of the hand have been destroyed by such a procedure. With accurate preoperative

radiographs and a bloodless field, the surgeon should be able to find what he is looking for

The Berman locator is at times a great help in locating small metallic objects which cannot be palpated deep in the forearm muscles One electrode is grounded to the patient, as with a Bouvie unit After the exploratory incision is made, the other electrode, a needle, is used to probe the wound When the foreign body is approached, the locator buzzes more loudly

FISH HOOKS—Fish hooks which are imbedded in the hand usually have the proximal end protruding If the hook has a heavy barb, removal by pulling the hook back out causes considerable damage There are two alternatives If no important structures will be traversed, the hook may be thrust on through until the point surfaces elsewhere and this end grasped with a forceps while the shaft and eye are cut off with a heavy pliers A second procedure, which produces less trauma than trying to tear the hook out, is to make an incision down to the barb and withdraw the hook, afterward closing the incision.

INDELIBLE PENCIL WOUNDS—Because aniline dyes are used in the production of indelible pencil leads, this wound presents a special problem A piece of lead broken off in the wound causes necrosis of the tissue which gradually spreads to the surrounding tissues, giving a swollen bluish appearance and producing a persistent draining sinus If these wounds are seen within a few hours, removal of the lead fragments and debridement of the stained tissue may suffice Treatment for late cases consists of removal of the necrotic pocket and all damaged tissue

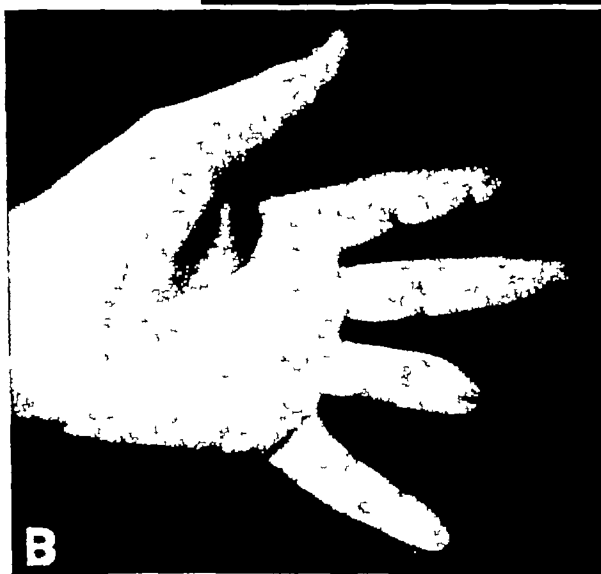
GUNSHOT WOUNDS

In most gunshot wounds of the hand caused by a bullet fired from a distance, the treatment should be conservative The wound of entrance and the wound of exit are debrided and the hand is splinted in the position of function with pressure dressings and kept elevated (Fig 29) X-rays are taken to ascertain the damage to bones and the usual test for nerve and tendon injuries carried out Quite often in civilian practice one sees cases in which a low velocity bullet has passed through the hand or the forearm without inflicting any great damage After the initial swelling subsides active exercise is carried out and no surgery may be necessary.

NAIL INJURIES

The fingernail serves an important part in the function of the hand The nail helps to pick up small objects from a smooth surface In pinch-





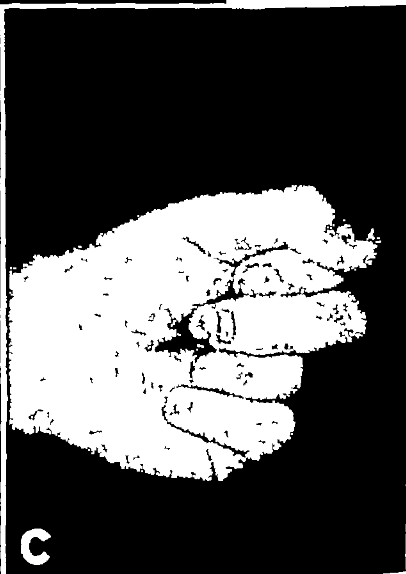


FIG 29—*A*, shotgun wound of hand Although ring finger required amputation, treatment otherwise consisted of conservative debridement and splinting in the position of function *B* and *C*, result three months later

ing, it backs up the pulp on the front of the finger, and with the phalanx it maintains the configuration of the finger It protects the end of the finger against sudden blows and, although insensitive to pain, conveys the sensation of touch

The growing part of the nail is intimately connected with the periosteum at the base of the distal phalanx and ends at the skin fold over the

base of the nail. Distal to this area, the nail bed or matrix is closely attached to the periosteum beneath it, binding the nail to the bone. The nail is also loosely attached to the fold of skin over its base Along the sides the skin fold is normally not attached to the nail This portion of the nail is sometimes spoken of as the wall The lunula or white half-moon at the proximal exposed portion of the nail marks the limit of the germinal layer

When a nail is bruised a hematoma develops beneath it. Such injuries should be x-rayed since a fracture of the terminal phalanx may be present Some treatment to relieve the pain caused by pressure may be indicated The nail may be drilled with the tip of a pointed scalpal or a hole may be burned in it with a red hot wire An electric cautery with a fine, sharp point heated to cherry red can be quickly thrust through the nail to evacuate a hematoma, without injury to the underlying nail bed The nail-drilling procedure may be used as a first aid maneuver When adequate medical facilities are available, it is much more satisfactory to evacuate a subungual hematoma by slipping a sharp, thin-bladed knife, such as a cataract knife, under the nail from the distal edge or under the fold

Simple lacerations of the nail in which the matrix is undisturbed are treated by cleansing the wound and strapping the nail down with adhesive As the nail grows out, the matrix will heal smoothly and no deformity will result Suturing of the nail is difficult and is rarely required

When the nail is torn away from the finger, the patient is usually made more comfortable if the loose part is cut away and the exposed matrix dressed with petrolatum gauze and protected for a week or two Sometimes the base of the nail is torn loose under the fold, leaving the distal half of the nail still attached When this occurs the nail base should be removed to prevent a paronychia-like irritation The distal nail may be left to protect the end of the finger

In more severe wounds the nail matrix may be torn loose from the underlying bone In these cases the adjacent nail is removed and the matrix then repaired with fine nonabsorbable sutures Any displacement of an underlying fracture is corrected at the same time and detached fragments of bone are removed The nail matrix is exceedingly tough and holds sutures well, the junction of matrix and skin should be accurately matched Dressings consist of petrolatum gauze, dry gauze and splinting After about 10 days the sutures are removed As the nail grows out, it will cross the scar and eventually a normal nail will result Sometimes the nail becomes detached from the matrix when it grows across the scar, causing the surface of the matrix distal to the scar to hypertrophy and

giving a dirty, warty appearance The patient should be taught to scrape off the warty material, file the nail down and keep it strapped down with adhesive. Eventually the nail should attach itself as far as the end of the finger

When the nail matrix has been pulled away from the bone at the nail root and lies outside the skin fold, it should be replaced using two or three sutures (Fig 30). Each suture is passed through the skin fold, then through the edge of the matrix and back through the nail fold When the sutures are in place, all are drawn tight at once, pulling the dislodged matrix back underneath the skin fold

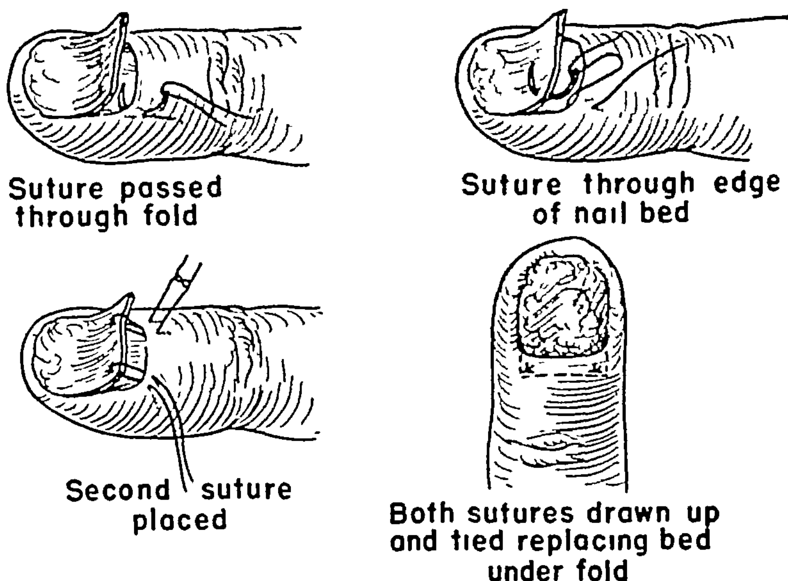


FIG 30—Technic of replacing nail matrix avulsed from its base The nail proper has been removed

Occasionally in machine tool injuries the entire nail bed together with the matrix and root is lost Immediate split thickness skin grafting will restore function and avoid amputation (Fig 31) When a part of the nail matrix is replaced with a skin graft, the nail will not adhere well to the grafted area In traumatic amputations of the tip of a digit, the nail matrix may be used to advantage in suturing flaps or skin grafts into place The matrix is hardy and will survive if carefully sutured back even when almost completely torn away Recent investigations indicate that the matrix slowly grows out from the base to cover the dorsum of the phalanx

The skin around the nail matrix is usually injured at the same time

the matrix is torn away. Accurate suture of the nail fold may be difficult, due to loss of tissue, but should always be attempted. The finest possible silk or wire sutures should be used

Adhesions which form between the nail fold and the underlying matrix give rise to a split nail This can be prevented by running a small probe under the fold at the end of two weeks or so when healing is fairly well advanced The adhesions are broken, and the space between the fold and the matrix is then kept open by running a probe in every day or two It takes six months for a nail which has been removed from a normal

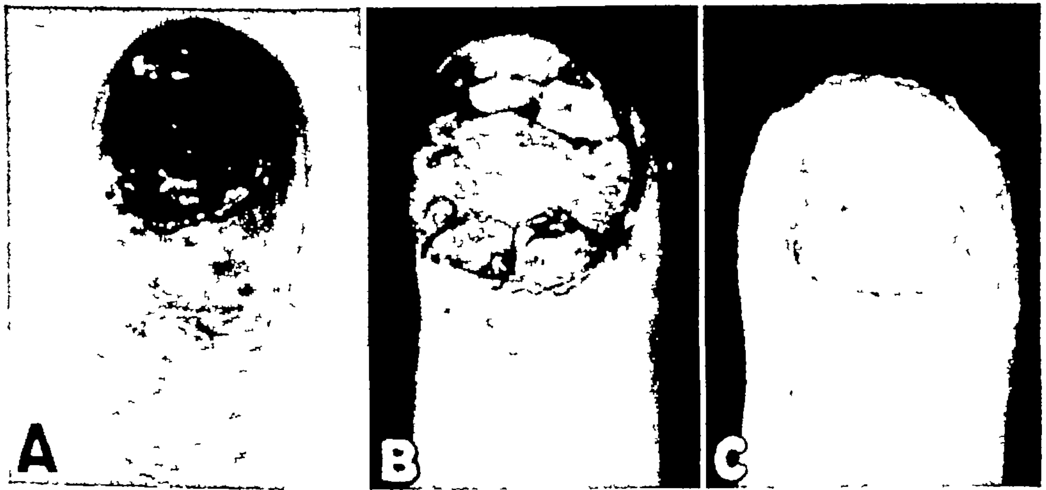


FIG 31—*A*, destruction of part of nail bed and underlying phalanx by routing machine Treated by immediate split thickness skin graft, with primary healing, *B*, at first redressing, *C*, when patient returned to work

finger to grow all the way out and it sometimes takes longer in a finger that has been damaged

ARTERIAL INJURIES

Acute traumatic vascular emergencies are fortunately rare in civilian life There are still some arterial injuries which are the result of surgical accidents, lacerations and penetrating wounds account for most of the other cases encountered The radial artery is occasionally injured in penetrating wounds of the anatomic snuffbox, and the superficial palmar arch is often severed in deep lacerations of the palm Bruising of the artery subcutaneously is commonly due to fractures or dislocations in the region of the shoulder or elbow Occasionally the axillary vein is thrombosed either spontaneously or as a result of trauma

Severe contusions of the vessels in crushing injuries may result in loss of circulation and gangrene The treatment of the patient as a whole as well

as the preservation of the extremity in such cases requires exceedingly fine judgment. It is better to carry out early exploration than to wait, hoping for collateral circulation to develop In severe cases, development of the crush syndrome must be anticipated

DIAGNOSIS —In arterial injuries the diagnosis is based on absence of pulse with a cold, white or mottled extremity Loss of sensation comes on some hours after loss of circulation.

TREATMENT —Although venous injuries as a rule respond to conservative management, including anticoagulant therapy, rest and elevation of the part, arterial emergencies require immediate definitive treatment. Treatment of arterial injuries may be divided into four stages first aid, hospital admission, definitive treatment and postoperative treatment

Rules for treatment —*Do not delay. Do not elevate Do not refrigerate Do not heat. Repair within 8 hours*

First aid —A tourniquet is applied to the extremity, this is loosened every half hour for one minute A pressure dressing is placed over the wound and the arm kept below heart level at an angle of 45 degrees from the body

Hospitalization —On hospital admission transfusions are given to combat shock, and morphine, Papaverine, antibiotics and oxygen are administered Do not disturb dressings if they are adequate Preparations are made for definitive treatment

Definitive treatment —A major surgical setup is necessary, with proper anesthesia and suitable arrangements to combat shock The surgeon must be able to restore continuity to the artery, using a vein graft if necessary

Incisions must be made where the vessels can be located and controlled proximal and distal to the site of the wound before exploring the area of trauma Crushing clamps should not be applied to the artery, rather, the ends of the artery are secured by special toothed arterial clamps The tourniquet is then released If the artery is mobilized for a considerable distance, end-to-end suture may be possible after excision of the damaged segment The classic Carrel technic of placing three stay sutures to triangulate the ends of the artery and making the anastomosis with a continuous everting mattress stitch has outlasted all innovations in arterial repair Whenever too much artery has been destroyed, a vein graft must be employed Either the accompanying vein or the superficial femoral vein is usually selected All bleeding must be controlled before the wound is closed

In an artery that has been lacerated but not severed, the injury may at times be controlled by suture When in doubt about the collateral circulation, the distal end of the artery should be released while bleeding

from the proximal end is temporarily controlled by pressure If free, continuous flow of blood occurs, repair of the artery may not be necessary

Ligation of either the radial or the ulnar artery alone causes no impairment in the nutrition of the hand. The principal risk in this procedure lies in the possibility of a subsequent accident damaging the only remaining artery Ligation is suitable in the forearm when only one of the two major vessels is severed Otherwise it is to be condemned. In one series of cases, of 15 patients who had the major artery to an extremity ligated, nine required amputations and one died

More successful arterial grafts or repairs are reported above the elbow than distal to the bifurcation of the brachial In the forearm the small size of the radial and ulnar arteries makes any operative procedure rather impractical I have successfully removed clots several inches long from both the radial and ulnar arteries and thereby restored circulation to an apparently doomed, cold, blue, insensitive extremity After exposing the vessels from the elbow to about 3 in above the wrist, a linear incision ⅛ in long was made in the arteries distally and the clots milked out Free bleeding followed, and the arteriotomies were closed and heparin injected intra-arterially * This case was classified as of thromboembolic origin

Attempts to restore the circulation by arterial or venous grafts below the elbow have not been successful in crushing injuries I believe that some of these arms might be saved by radically shortening the bone and soft tissues and the vessels with end-to-side arteriorrhaphy

Each finger actually has four arteries Besides the volar arches, there is a dorsal arch across the back of the wrist, with branches extending down between the metacarpals and forking to supply the adjacent sides of each finger, and a branch from the radial which supplies the back of the thumb In addition to the radial and ulnar arteries, there is a volar interosseous artery in the forearm which arises from the ulnar artery near its origin and passes down the center of the forearm on the interosseous membrane Occasionally the volar interosseous artery and the dorsal interosseous branch, which runs down the dorsum of the median side of the ulna, will supply enough blood to nourish the hand even if the radial and ulnar are interrupted Similarly, it sometimes happens that a finger will survive if both proper volar digital arteries are severed

Postoperative treatment—Postoperative management of these patients includes use of antibiotics, paravertebral sympathetic block and anti-

*Robert Linton of Boston removes clots from arteries by retrograde injection of heparin solution

as the preservation of the extremity in such cases requires exceedingly fine judgment It is better to carry out early exploration than to wait, hoping for collateral circulation to develop In severe cases, development of the crush syndrome must be anticipated

DIAGNOSIS—In arterial injuries the diagnosis is based on absence of pulse with a cold, white or mottled extremity Loss of sensation comes on some hours after loss of circulation

TREATMENT—Although venous injuries as a rule respond to conservative management, including anticoagulant therapy, rest and elevation of the part, arterial emergencies require immediate definitive treatment. Treatment of arterial injuries may be divided into four stages first aid, hospital admission, definitive treatment and postoperative treatment

Rules for treatment—*Do not delay. Do not elevate. Do not refrigerate Do not heat Repair within 8 hours*

First aid—A tourniquet is applied to the extremity, this is loosened every half hour for one minute A pressure dressing is placed over the wound and the arm kept below heart level at an angle of 45 degrees from the body

Hospitalization—On hospital admission transfusions are given to combat shock, and morphine, Papaverine, antibiotics and oxygen are administered Do not disturb dressings if they are adequate Preparations are made for definitive treatment

Definitive treatment—A major surgical setup is necessary, with proper anesthesia and suitable arrangements to combat shock The surgeon must be able to restore continuity to the artery, using a vein graft if necessary

Incisions must be made where the vessels can be located and controlled proximal and distal to the site of the wound before exploring the area of trauma Crushing clamps should not be applied to the artery, rather, the ends of the artery are secured by special toothed arterial clamps. The tourniquet is then released If the artery is mobilized for a considerable distance, end-to-end suture may be possible after excision of the damaged segment The classic Carrel technic of placing three stay sutures to triangulate the ends of the artery and making the anastomosis with a continuous everting mattress stitch has outlasted all innovations in arterial repair Whenever too much artery has been destroyed, a vein graft must be employed Either the accompanying vein or the superficial femoral vein is usually selected All bleeding must be controlled before the wound is closed

In an artery that has been lacerated but not severed, the injury may at times be controlled by suture When in doubt about the collateral circulation, the distal end of the artery should be released while bleeding

begun after about two weeks. Some limitation of motion may be anticipated after this type of wound, but if treatment is properly carried out full function is eventually obtained

SOFT TISSUE DAMAGE, JOINT DISRUPTION AND CONTAMINATION — In the third type of wound the contamination is rather extensive, the joint is disrupted and the soft tissues are also damaged. If these wounds are seen early and some sort of primary restoration of the bones and covering with soft tissue is possible, repair should be undertaken. This is particularly true if the contamination is not severe and the injury is less than six hours old If the injury is more than six hours old and there is considerable contamination, primary repair may still be effected provided the operator is able to convert the wound into a clean one and the patient can be kept under close observation In these cases, the soft tissue should be closed very loosely with widely placed, interrupted sutures The deep structures present a serious problem If much of the bone around the joint is removed, future disability will be great, due either to instability of the joint or to stiffening On the other hand, if nonviable fragments of bone are left, infection may be anticipated.

Delayed primary closure may be adopted, the bony structures being replaced and the skin wound packed open After four or five days secondary suture is carried out This method works well for the larger joints in the body but usually is not applicable to the small joints in the hand Generally speaking, a badly damaged joint will heal under optimal conditions but will remain stiff If considerable disruption is present, primary amputation may be the treatment of choice

A further discussion of treatment of joint injuries complicating extensor tendon lacerations will be found in Chapter 9

coagulant therapy with heparin and Dicumarol in adequate dosage Heat is contraindicated

JOINT INJURIES

Wounds of the hand frequently enter the joints and, if neglected, may be complicated by serious infections For example, a truck driver suffered a minor laceration over the proximal interphalangeal joint of the long finger as a result of bumping it on the instrument board He reported to a physician in the next town who dressed the wound but applied no splint As he continued on his transcontinental run, the finger gradually became more painful Dressings were changed at intervals A suppurative arthritis developed which eventuated in amputation of the finger Similar tragedies have followed puncture wounds of the metacarpophalangeal joint (Fig 174).

The treatment of joint wounds has changed considerably with the advent of antibiotic and chemotherapy Formerly, there was a high incidence of infection after primary closure of joint wounds Now, the severity of infection has been greatly reduced and with proper treatment primary infection can be practically eliminated The treatment of choice depends to a certain degree on the extent of the injury, the time since injury and the amount of contamination

PUNCTURE WOUNDS—The simplest type of joint injury is the puncture wound, which occurs from through-and-through wounds by sharp objects and also from trivial lacerations over the dorsum or lateral aspects of the finger joints Small-caliber bullet wounds of the wrist also come under this classification Proper treatment for these injuries is conservative The wound should be cleansed and any foreign body removed The extremity should then be splinted in the position of function and antibiotics given

SOFT TISSUE DAMAGE WITHOUT JOINT DESTRUCTION—The second type of wound shows considerable soft tissue damage without destruction of the joint and with not too much contamination These wounds should be thoroughly explored and, if indicated, the joint should be opened to remove loose particles of cartilage, small fragments of bone and foreign bodies The wound should then be closed by any means possible, fashioning flaps or positioning the joint to cover the joint cartilage and applying a skin graft to fill in any defect When there are defects in the skin over the dorsum of the knuckles and the joint would consequently be left open, a small skin graft will often provide closure and eliminate future disability Splinting and antibiotic therapy are used routinely. Motion is

begun after about two weeks Some limitation of motion may be anticipated after this type of wound, but if treatment is properly carried out full function is eventually obtained.

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CHAPTER FOUR

Amputations

THE INDICATIONS and technics for amputations performed as emergency procedures are entirely different from those for elective amputations In the upper extremity, most amputations are the result of trauma and require emergency treatment Those carried out because of thermal injuries, nerve injuries, tumors, vascular disease or infection are usually elective procedures The technical problems encountered in the latter type are described briefly in Chapter 14

GENERAL PRINCIPLES—In amputations of the digits and hand the surgeon should remember that usefulness and durability are the chief objectives Appearances are secondary and symmetry is of no consequence In most cases no set amputation is applicable By removing devitalized or damaged tissues and fashioning impromptu flaps, often a surprisingly useful finger end can be made if kindly healing occurs Before any part is removed from the hand, one must consider, first, what is to be gained by the amputation and, second, what the probable outcome will be

Fingers are often severed in industry by machine tools, punch presses, etc, or at home with an axe, lawnmower or fan, and the excited patient seeks care at the nearest physician's office or emergency room Because of the seeming urgency of the injury to the patient and the apparent triviality of the injury to the physician, much treatment is poorly carried out in haste that could better be done more slowly and considerately Actually, there is no need to operate immediately The wound should be covered with a sterile dressing and the patient transported to a hospital where adequate x-ray, anesthesia and surgical facilities are available

Hemorrhage and shock.—The apparent bleeding, as judged by the blood on the dressings, is greater than the actual blood loss The more serious injuries resulting in amputation often bleed little if any. To control hemorrhage it is first necessary to quiet the patient and elevate the part The patient should therefore lie down and be given an opiate, and the attendant or surgeon should elevate the part and apply dry gauze with pressure Usually at the accident some misinformed first-aider has applied a tourniquet which is only tight enough to compress the veins, thus increasing bleeding This constricting band should be removed Occasionally an arterial pumper will be plainly seen; if this vessel can be grasped with a sterile hemostat without hurting the patient or disturbing the rest of the wound, this may be done. An assessment of the amount of injury and a tentative plan of repair can now be made

Examination and classification.—Depending on the type of injury, the problem encountered usually falls into one of two large classifications Either the finger is already severed and a new end for it must be made, or the finger is so badly damaged that repair is not possible and amputation must be carried out, conserving what may be useful (Fig 32)

Before surgery an x-ray should be taken routinely because there often are spicules of bone in the soft tissues or associated fractures which might otherwise be overlooked The x-ray also acts as a record to protect the surgeon against malpractice suits. The patient's occupation should be ascertained, because to a certain extent the treatment is governed by how the patient uses the hand in his work It is useless, for example, to apply a pedicle flap to cover the end of a finger of an unintelligent workman or an elderly stiff-jointed patient because he will object to the absence of sensation and will often request amputation later On the other hand, patients with sedentary occupations often appreciate the appearances of a hand and will tolerate a finger which lacks something in mobility or sensation

TREATMENT OF COMPLETE TRAUMATIC AMPUTATIONS

When the finger has been fairly cleanly severed, the problem is actually one of wound healing and not of amputation For these cases, debriding the wound, removing devitalized tissue, smoothing off the projecting bony spicules, controlling hemorrhage and skin grafting usually give a good result If the result is not satisfactory, a minor revision may be made later If a formal amputation is indicated, the result will be better if this is carried out after the skin graft is healed than if it is done at the time the tissues are torn up by the original injury.

TECHNICS —In preparation of the wound and anesthesia the routine described in Chapter 2 should be followed Mechanical cleansing of the part is essential Loose epidermis and tags of crushed tissue, as well as loose pieces of bone, projecting spicules, dirt and blood clots, should be removed. Antiseptics may be used on the intact skin but only

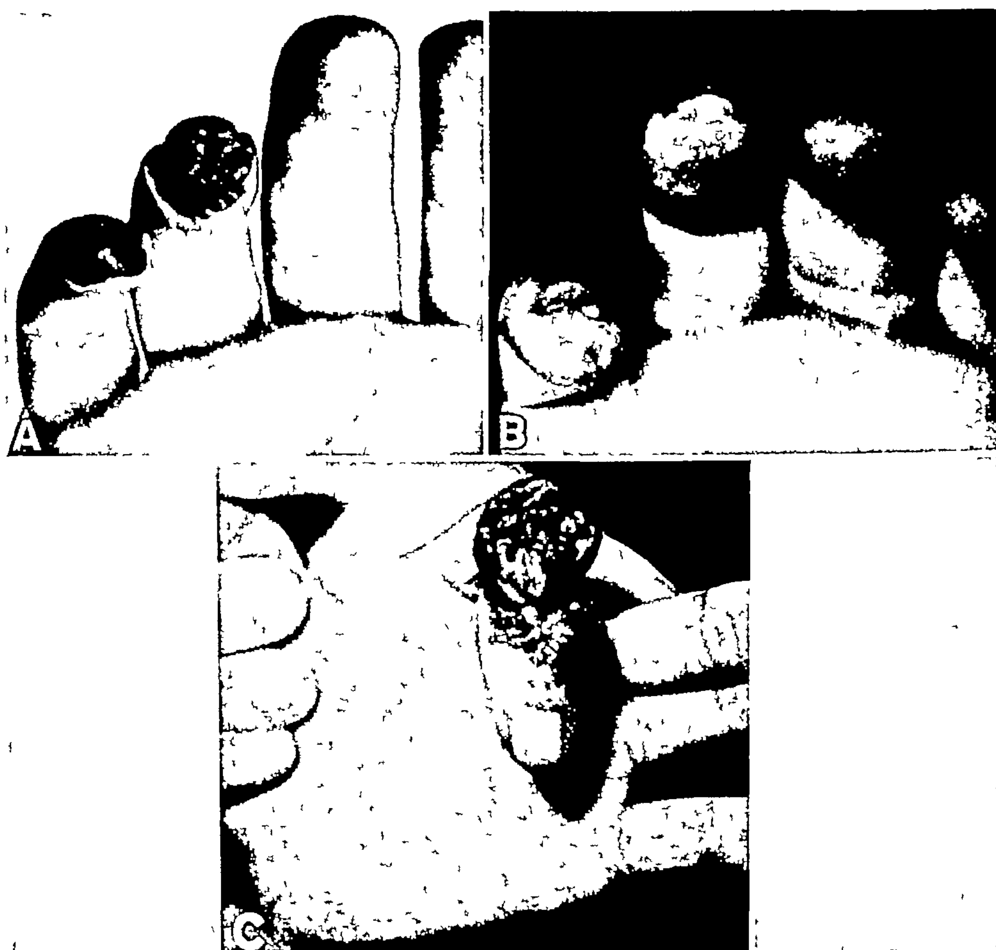


FIG 32 —*A*, tips of two fingers cut off by saw, *B*, after skin grafting This is about the shortest level at which skin grafting is appropriate (base of nail) *C*, badly damaged finger requiring amputation

saline on the open wound In simple cases treatment may be carried out with local anesthesia in an emergency room A ring anesthesia injected ½ in proximal to the amputation site is adequate and helps to control bleeding When the tissues are stained with grease the edges may be excised slightly to get rid of the discolored tissue Even if some stained tissue is left, healing will not be impeded if the wound is clean and viable although later removal (for cosmetic reasons) may not be practical

Nerves—In the terminal segment of the finger no attention is usually directed to the digital nerves In the middle and proximal segments the digital nerves should be picked up, pulled down ¼ in or so, cleanly severed with sharp scissors or a knife and the ends allowed to retract into soft fat This precaution is also worth while when flaps are formed, thereby avoiding the formation of a painful scar Neuromas always form when nerves are cut The surgeon should attempt to locate the nerve ends where they will not be caught in scar or exposed at the end of a stump

Arteries—In the proximal and middle segments of the finger, the digital arteries often require ligation If possible, the arteries should be drawn out a short distance from the end of the finger, a ligature applied, and the end of the artery then snipped off, allowing the ligated end to be retracted into the tissues

Bones—The amount of bone to be removed before applying a skin graft or impromptu flap to a cleanly severed finger should be minimal When a skin graft is to be applied, just enough bone should be removed to keep the bone from projecting beyond the adjacent skin When flaps are used, enough bone should be left to support the end of the finger Aside from removing projecting spicules so that the bone feels fairly smooth to the surgeon's gloved finger, it is not necessary to contour or otherwise shape the bone The only exception to this is when the amputation line runs through a joint

Joints—When the amputation line runs through a joint, the cartilage should be removed from over the bone end and the condyles rongeured away so that the resulting bone peg is cylindrical or shaped like a phalangeal tuft

If the joint capsule is attached by a broad base, it may be salvaged and sutured over the end of the contoured bone to form a base for a split thickness skin graft The extensor aponeurosis may at times be used in a similar manner Either of these structures, when used, should be sutured in place with a nonabsorbable suture such as wire which is passed out through the skin and later withdrawn When the amputation runs through a joint in the middle or ring fingers, enough bone should be removed so that the stump will not project beyond the corresponding segment of the adjacent fingers

Tendons—In traumatic amputations no attempt should be made to fix the tendons in the wound The extensor tendons which lie in a thin layer between the skin and the bone on the back of the finger will not retract much and will function perfectly if simply severed at the level of the wound The flexor tendons often retract in their sheaths and, if this

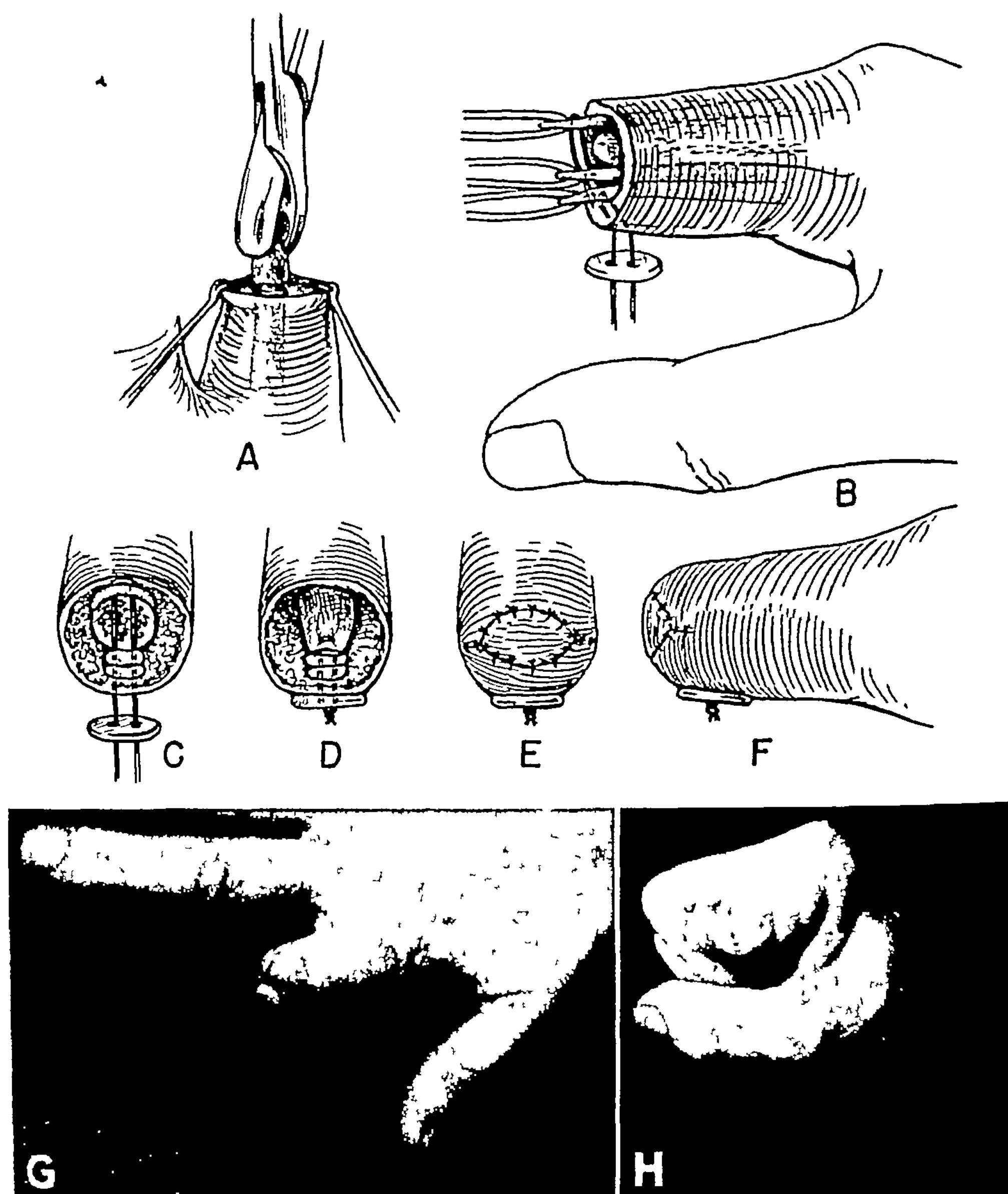


FIG 33—Amputation method in proximal segment of finger when added length may be indicated because of loss of adjacent digits (If remaining digits are normal, a flap amputation sacrificing tendons is preferred) *A*, bone rounded, *B*, tendons balanced, *C* and *D*, removable wire suture used to cover bone end with joint capsule, *E* and *F*, skin partially closed and remaining defect covered with split graft. *G* and *H*, finger treated by this method at first redressing, full function This method is only to be used in exceptional cases (See text, page 81)

occurs, no harm will be done if they are left alone provided no infection-causing material has been introduced into the sheath Such tendons will usually be found later to have attached themselves to the inside of the digital sheath and will aid in flexing the finger stub No advantage is

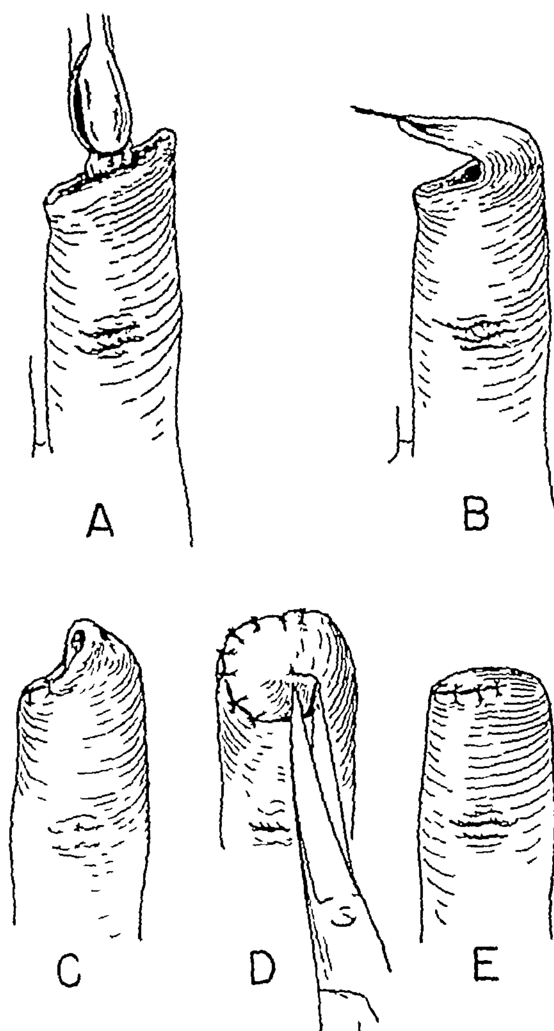


FIG 34—Technic for lateral flap *A*, bone rounded *B*, thinned flap brought over end of finger *C–E*, suture of flap with removal of dog-ear

gained in attaching the profundus tendon to the middle segment of the finger because, although there may be some increased power from the extra muscles, usually some stiffening results due to the two flexor tendons not functioning together In the proximal segment of the finger nothing remains to mobilize the fingers except the interossei, so that at times in the strong index and middle fingers added power may be supplied by using one of the flexor tendons (Fig 33) This maneuver is principally

indicated when only shortened digits remain This tendon should preferably be attached to the sheath by a mattress suture of wire which can be withdrawn through the skin Under no circumstances should any heavy suture material be interposed between the end of the bone and the flap covering it If only one finger is cut off, the flexor tendon had best be drawn down, cut off short and allowed to retract so that it will not checkrein the other fingers

Flaps—A tag of skin of sufficient size to cover the denuded end frequently will be found adjacent to the site of injury (Fig 34) Although the circulation of such a flap may not seem adequate, the flap will usually remain viable if it is carefully sutured into place over a dry, properly

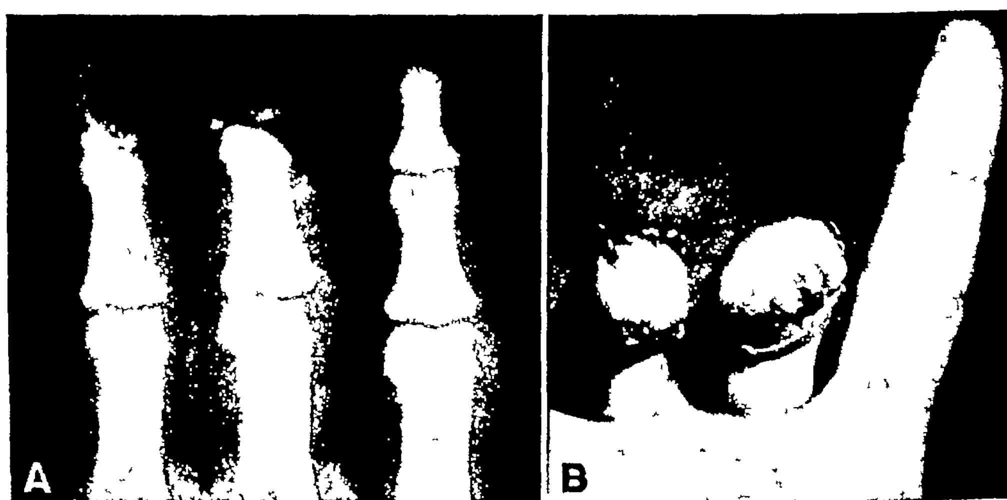


FIG 35—*A*, distal phalanges of two fingers destroyed by sawcut In wound closure existing skin was used for flaps, long finger has dorsal flap, ring finger lateral flap *B*, appearance at first redressing

dressed field If adequate, the flap need not be of palmar origin A lateral flap or a dorsal flap, depending on the obliquity of the wound, may be used (Fig 35) The chief difficulty with large palmar flaps is that they may be too heavy and thick In using impromptu flaps the technic to be followed is to remove just enough bone to allow the tip of the flap to be brought across to the opposite side of the finger (Any bony spicules adherent to the flap are usually best removed) A suture is inserted at this point and the rest of the flap then trimmed with sharp scissors to obtain a smooth, tensionless suture line

Skin grafts—When no flap is available, the finger being cleanly severed, the problem in wound healing is met by applying a skin graft A split thickness skin graft removed with a razor (Fig 36) has much

more chance of success on fresh amputations than a full thickness graft. If a dermatome is available, anyone doing this type of surgery can quickly learn to remove small skin grafts to graft finger tips and similar-sized defects on the hand The technic is described in Chapter 6 In adults a 0 015 in thick piece of skin may be removed from the lateral or anterior surface of the thigh without causing any inconvenience or scarring The donor site is dressed with petrolatum gauze and pressure and will be found to have healed when the dressing is removed at the end of two weeks

The skin graft is laid over the end of the finger and trimmed to fit with sharp scissors It is sutured in place with interrupted fine silk sutures which are cut long and used to hold the dressing in place (Fig 37). In the terminal segment of the finger, the nail remaining should be re-

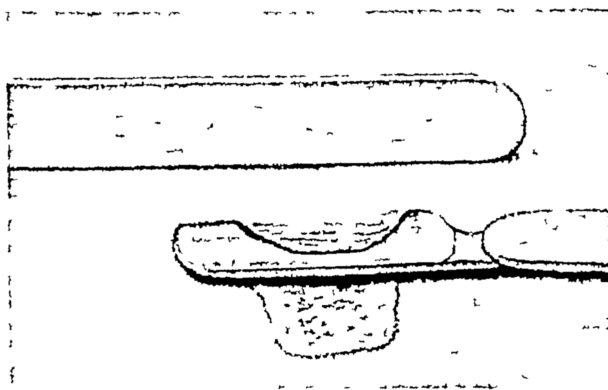


FIG 36—Removing small graft with razor

moved and the graft sutured to the nail bed All bleeding must be controlled before the graft is applied Usually the smaller vessels can be controlled with forcipressure applied foi a few minutes while the graft is being taken Ligatures, except of the finest possible material, should be avoided After the graft is in place, a thin layer of petrolatum gauze is applied and a cotton ball the size of the diameter of the finger placed directly over the gauze This is held in place by tying the long ends of the sutures across it Skin grafts applied in this way may be used on any level of the finger and will often give results comparable to full thickness flaps

POSTOPERATIVE CARE—For any type of amputation, the dressings should be applied so that a modest amount of pressure is made on the end of the finger to prevent hematoma formation The rest of the finger is covered with nonconstricting, adequately padded dressings A four-

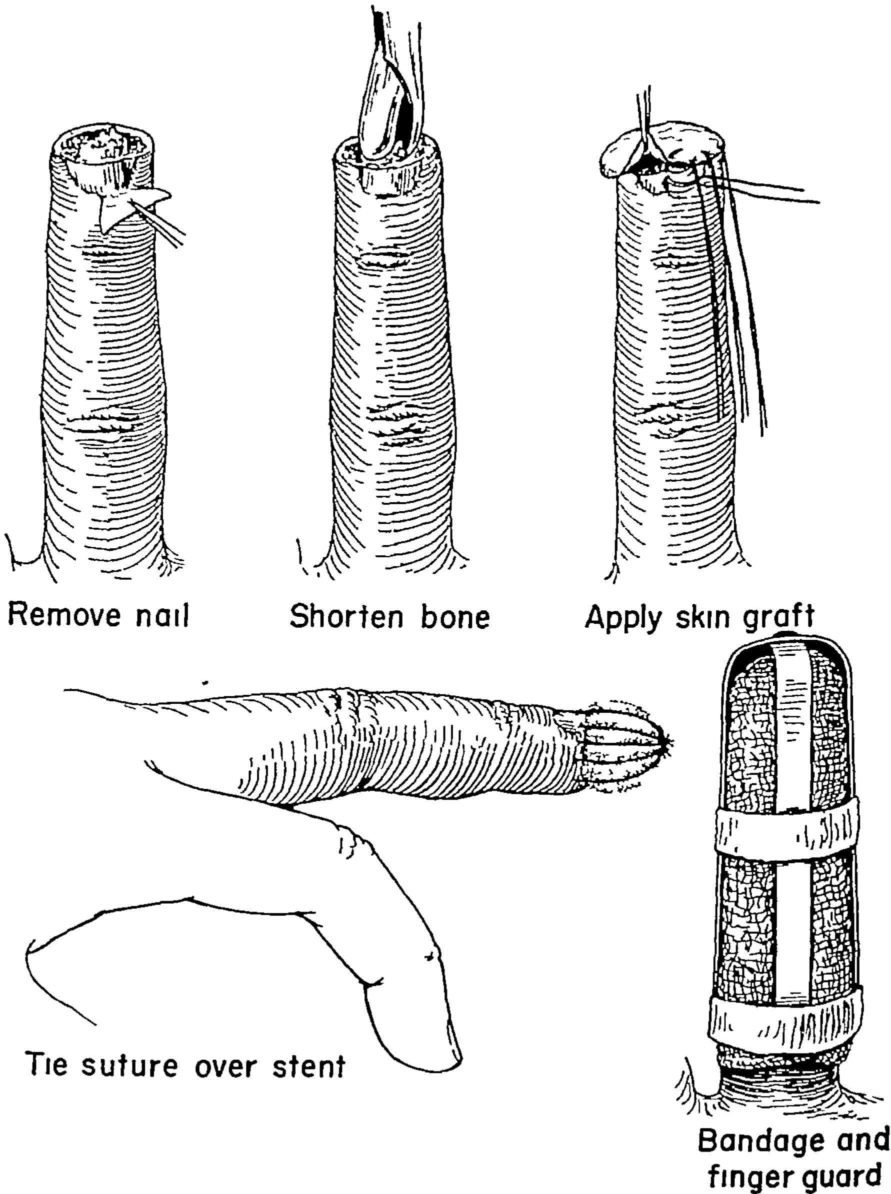


FIG 37 —Skin grafting technic for distal segment of finger Figure 32, *B*, shows results with this technic

pronged metal finger guard is shaped to fit the finger loosely, and after the finger is carefully bandaged with gauze the guard is fastened in place with Elastoplast or adhesive tape

The patient may be ambulatory and need not stay in the hospital after the initial shock and discomfort are relieved A well performed skin graft or flap amputation should not be uncomfortable and usually causes no pain Although not strictly necessary, one of the long-lasting antibiotic

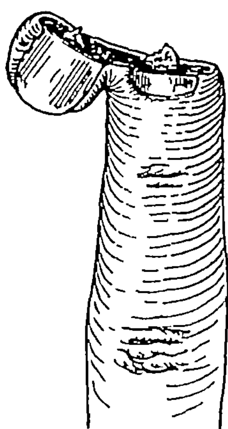
preparations is usually administered The patient is instructed to keep the finger clean, dry and elevated Unless complications ensue, the dressings, especially after grafting, should not be changed for about seven days At this time the sutures may be removed and the skin graft or flap will be found to have achieved early healing Further petrolatum dressings are applied and the finger then dressed at weekly intervals and kept protected with a finger guard for about three weeks. During this time some workmen may resume their normal occupations, but working should be discouraged during the first week because of the likelihood of traumatizing or wetting the wound.

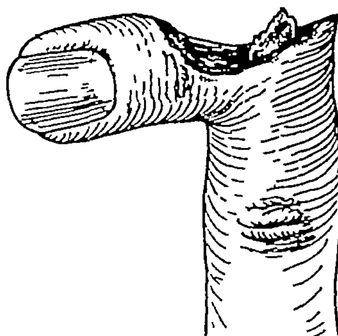
COMPLICATIONS—Few complications occur if the procedure is properly carried out. Occasionally, a hemorrhage under the skin graft or flap may be due to trauma or an improperly controlled vessel. A hematoma under a skin graft always results in separation of the graft and failure of the procedure When this occurs it is probably more practical to allow the wound to heal spontaneously, although regrafting is perfectly all right Healing will occur in about four to six weeks if the wound is dressed about twice a week with petrolatum gauze and granulations kept in abeyance by applications of silver nitrate The petrolatum gauze may be replaced by a latticework of adhesive strips as healing progresses to aid epithelization

Stiffness may be prevented during convalescence by encouraging the patient to move the uninvolved joints freely and otherwise use the extremity normally

EMERGENCY AMPUTATIONS FOR SEVERE INJURIES

INDICATIONS—The second type of emergency finger amputation is that done when the finger is so badly damaged that there is no possibility of saving it Most damaged fingers can be made useful by proper primary treatment and later reconstructive procedures The indications for amputation are not too numerous *Loss of blood supply,* when complete, will inevitably lead to gangrene Often gangrene will develop if both digital arteries are severed Occasionally, however, a finger may be adequately nourished by only one of the small dorsal arteries (Fig 38) If one flap of skin complete with digital vessels and nerves remains intact, the finger may be preserved and later restored to function even though all other structures, including tendons, bone and the rest of the skin are divided (Figs 39 and 40) Injuries proximal to or involving joints are more difficult and disabling than injuries of the distal segment Frequently,





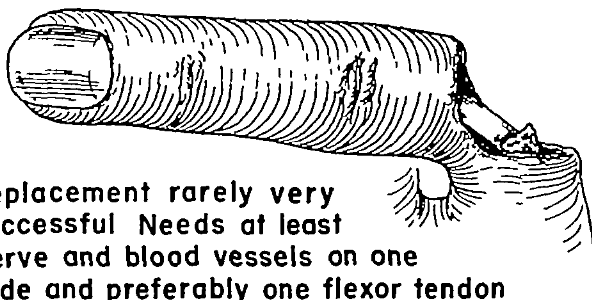


FIG 38 —Incomplete amputation Probable outcome at different levels (see also Figs 39-41, 156 and 158)



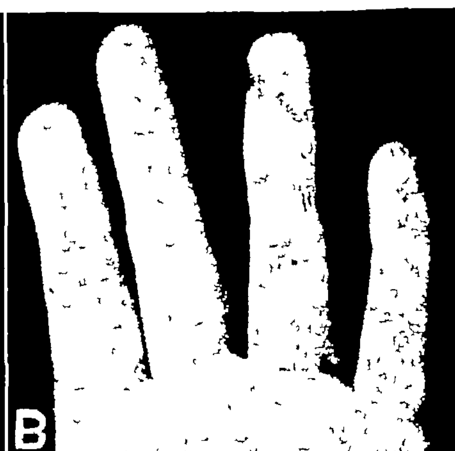


FIG 39 —*A*, incomplete amputation of finger proximal to nail bed *B*, end result after repair by reducing fracture, suturing soft parts and prolonged splinting

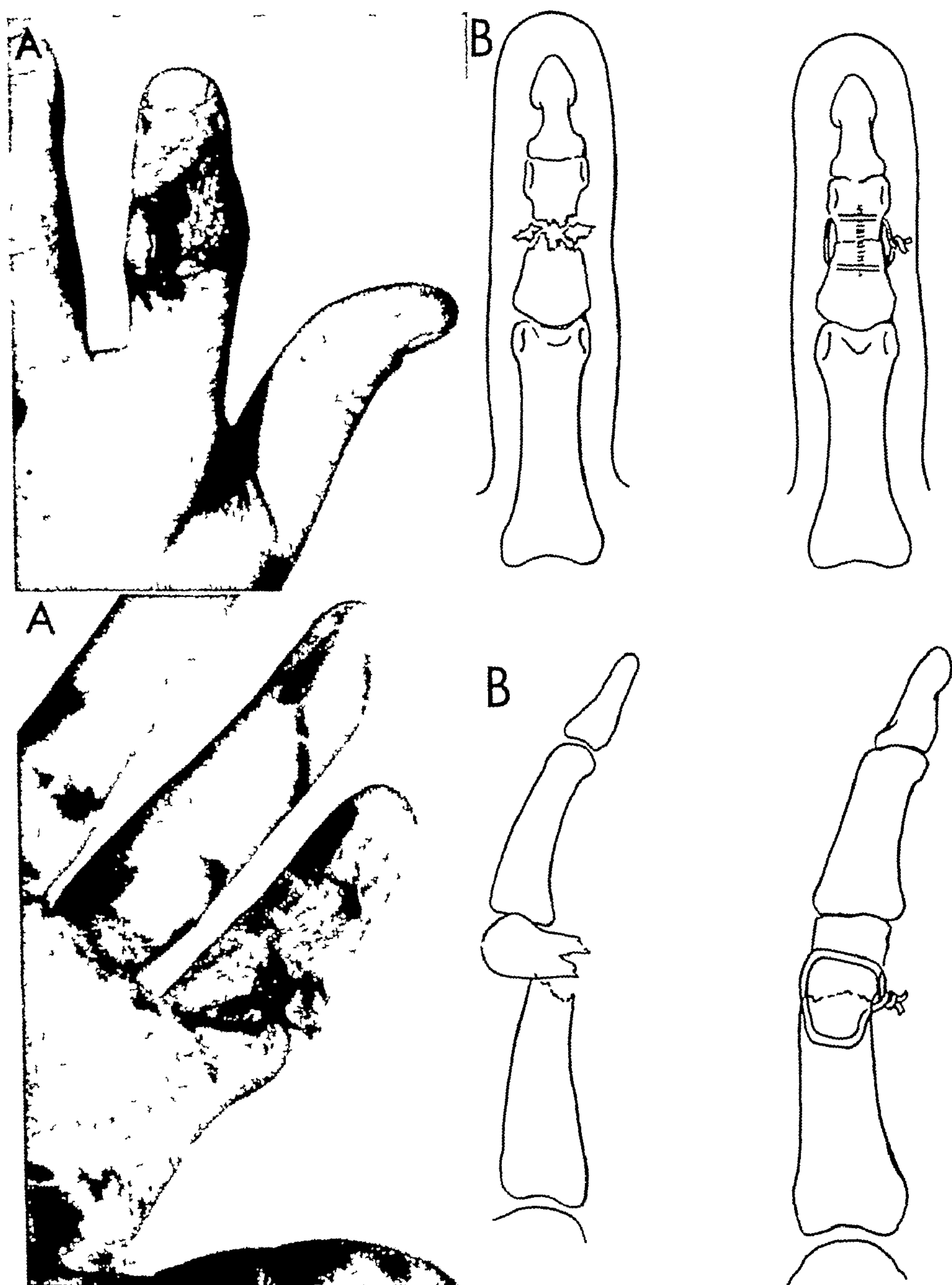


FIG 40 *(above)* —*A*, finger almost amputated in middle segment Loss of soft tissue necessitates bone shortening for successful replacement *B*, technic, bone was shortened ¼ in

FIG 41 *(below)* —*A*, finger almost amputated in proximal segment, replaced with good result *B*, technic

they can be repaired (Figs 40 and 41) Crushing injuries are more apt to result in loss of circulation than are lacerations (Fig 42)

Next in importance to loss of circulation is *extensive trauma rendering successful repair unlikely* Extensive compound fractures with concomitant

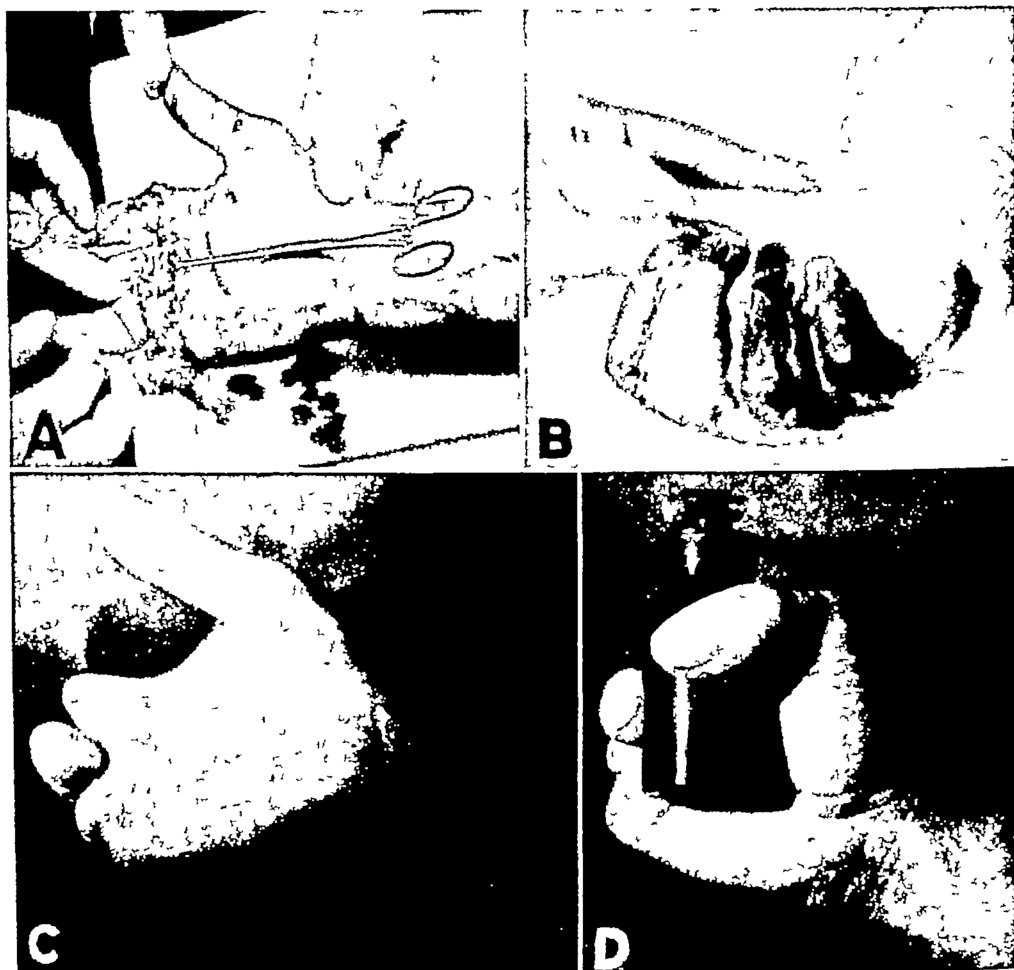


FIG 42—*A,* injury to hand caught between cable and pulley *B,* three days after primary repair gangrene of all except dorsal skin of long finger occurred, necessitating amputation Dorsal skin was used as a flap to cover the palm of the long finger, thus giving the thumb a digit to work against. *C* and *D,* end result, pinch and grasp motion preserved

destruction of tendons and joints would make reconstruction improbable In this connection, the extent of injury to other digits and the rest of the hand must be considered If only one digit is badly mangled and the rest of the hand is all right, it is sometimes more practical to sacrifice this finger and preserve a good, useful hand On the other hand, if all the

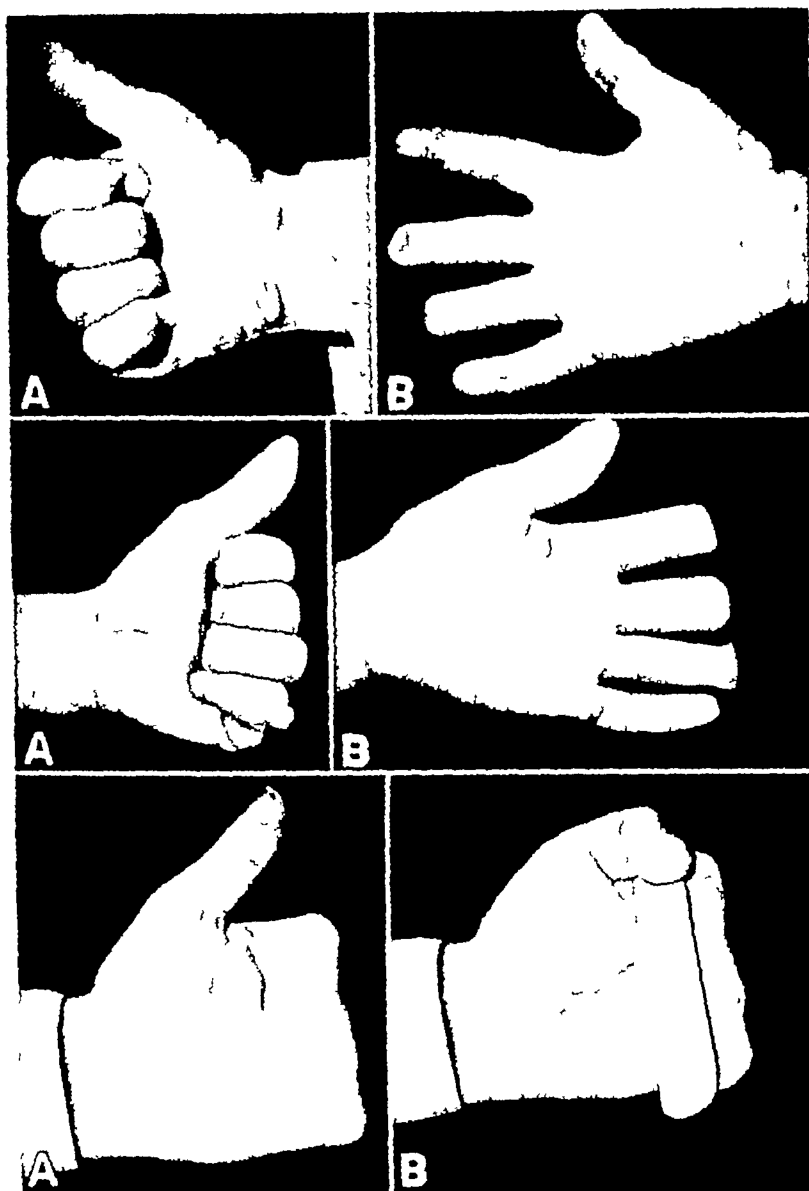


FIG 43 *(top)* —Ends of all fingers severed by planer Distal joints were preserved by primary skin grafting of finger ends and patient resumed occupation as dentist *A* and *B* show almost normal function obtained

FIG 44 *(center)* —Guillotine-type amputation through middle phalanges of three fingers With primary skin grafting, wounds healed with good use of hand *A* and *B*, appearance after three weeks

FIG 45 *(bottom)* —Crushing injury required primary surgical amputation through base of proximal phalanges *A* and *B*, limited pinch and pusher action resulting Length should not be sacrificed to get padding in this location

fingers are mangled, an attempt should be made to preserve them all, if possible, making an elective amputation later according to the needs Similarly, if all the fingers are severed, the ends of all should be skin-grafted, regardless of the level, as shown in Figures 43–45

The thumb should always be preserved no matter how badly it is shattered, because even a stump, though no more than a post, is useful in opposition to the fingers Extensive loss of soft tissues of a digit does not demand amputation The application of skin grafts or a pedicle flap (Chapters 6 and 7) and other reconstructive procedures will produce a useful digit, and when there is complete loss of the other digits such procedures may be imperative

The most difficult structures to repair are joints, and badly damaged joints are often an indication for amputation This might better be done after the patient has had a chance to try the finger and assure himself that it is useless

TECHNIC —*Preparation* —In converting the more severe type of injury into an amputation, the surgeon should preferably make use of major operating room facilities It is often better to use general anesthesia, because the extremity can then be more carefully cleansed and a finger for which treatment at first seems hopeless may at times be salvaged with the help of the additional facilities available The extremity is prepared and the wound debrided The instruments used are discarded and the wound again cleansed with saline solution after bleeding points are ligated The various tissues should be replaced in a natural position to determine how much of the finger is missing If it then becomes apparent

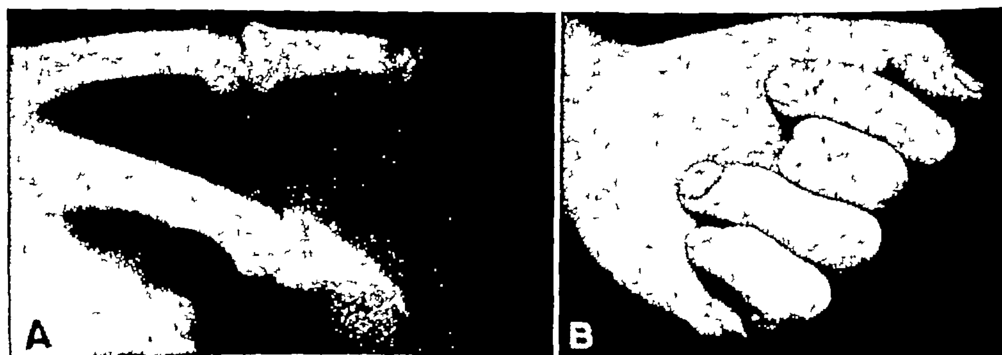


FIG 46 —Planer injury completely avulsed dorsal skin and extensor tendon and destroyed middle and distal phalanges of middle finger In repair, palmar flap was used to cover entire middle segment *A*, postoperative x-ray *B*, appearance after defatting

that immediate or future restoration is impossible, amputation may be undertaken.

Flaps.—With extensive bone and joint destruction there is often a large loss of soft tissue which may involve the entire dorsum or one com-

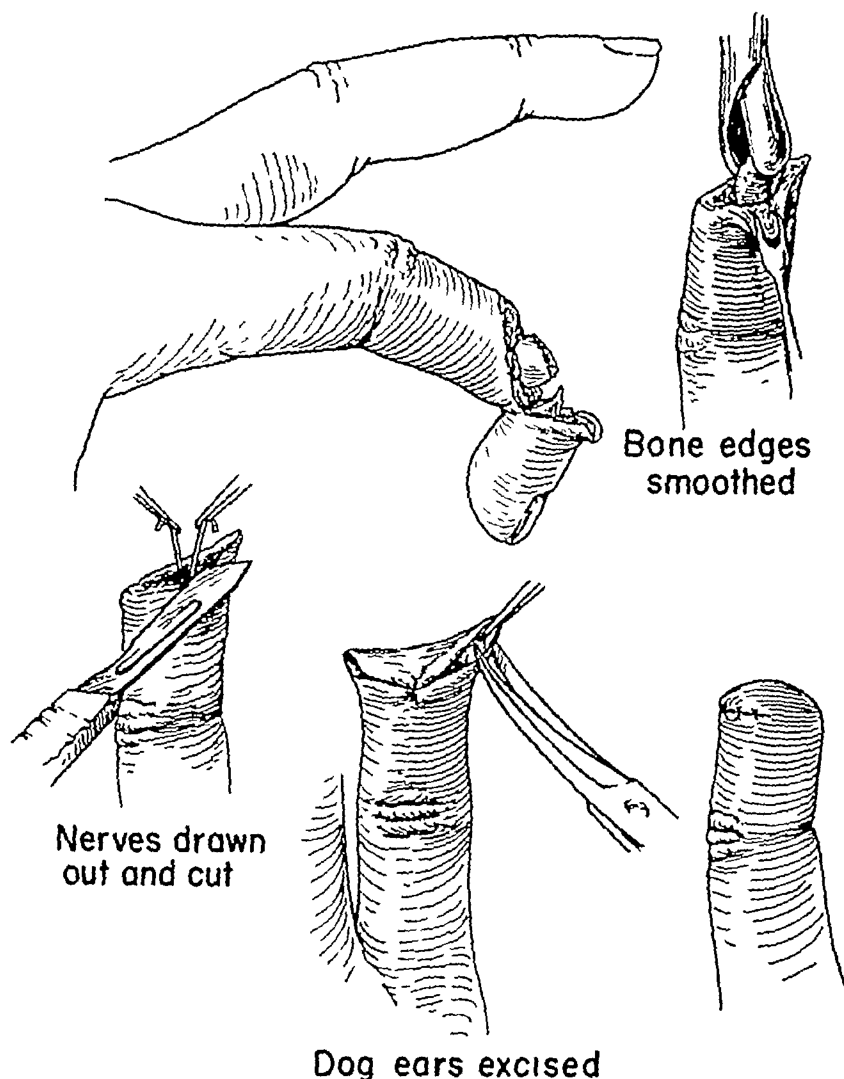


FIG 47—Technic for volar flap in incomplete oblique amputation where blood supply is lost. Existing line of tissue is used without sacrificing length

plete side of the finger. If the other side of the finger is intact, it may be filleted and used as a flap to cover up to one-half the finger. When this is done, the skin with its blood vessels and nerves alone should be saved, the joint and tendon structures remaining attached to it being completely removed If a large volar flap is thus used to cover the dorsum, it should be partially defatted or the finger will be too bulky. If care is taken to

avoid too sharp angulation with resulting compression of the circulation, such a flap will be very successful (Fig 46) The blood vessels and nerves in the flap are preserved, and there are good sensation and padding on the end of the stump

In making flaps one should avoid the tendency to have them too long and heavy The ability to make an amputation with a long palmar flap and a dorsal scar usually means that more finger has been sacrificed than is necessary If the flaps are carefully trimmed to fit with a sharp scissors or scalpel and are sutured into place with fine nonabsorbable sutures, carefully everting the edges, a scar may be made directly over the end of the finger. Such a scar is perfectly satisfactory and painless, and with the passage of time the functional result will be just as good as that with a long palmar flap Treatment of each tissue encountered should be properly carried out as described under complete traumatic amputations (Fig 47)

Avoiding painful stumps—Traumatic amputations often result in painful stumps, usually because the injury is of a crushing or tearing type, with partial devitalization of the skin The result after repair is much scarring from delayed healing, inadequate padding and nerves caught in the scar Other causes of tenderness are regeneration of a spicule of nail, formation of a sharp bony spur, formation of a bursa over a joint surface, and tendons which pull upon nerves Understandably, some of these conditions are unavoidable when an attempt to save length is made in badly damaged fingers Attempts to save length are commendable, but I believe that they should not be overzealously employed In most fingers, painful stumps after amputation can be attributed to delayed healing or to improper technic

Relative Importance of Fingers and Stump Lengths

The relative importance of the fingers should not be considered at the time of primary amputation or repair Whatever disagreement exists on this subject, in the final analysis the patient's occupation determines the use to which the finger is placed Stenographers and musicians, for example, require all of their digits, whereas laboring men do not A stiff finger which is flexed makes a hook which may be utilized in lifting things but is a hindrance for working in narrow spaces The little finger has much less power than its mates but is relatively less in the way when crippled The index finger, when normal, is most often used to oppose the thumb in picking up small objects, but if this digit is tender, stiff or

too short, the thumb will be opposed to the middle finger, and in some occupations the index finger will actually be a handicap by being in the way of the thumb. The middle and ring fingers have considerable power but have less dexterity than the index finger, and the ring finger is often less sensitive The ring or middle finger, when co-ordinated with the other fingers, functions well even if only a part of the proximal segment remains If one of these digits is removed entirely, leaving the metacarpal head in place, the remaining fingers may angulate toward each other, cupping the hand, and some in-co-ordination is occasioned thereby. Small objects are dropped through the gap in the hand

The surgeon who follows the technic outlined in this chapter need not

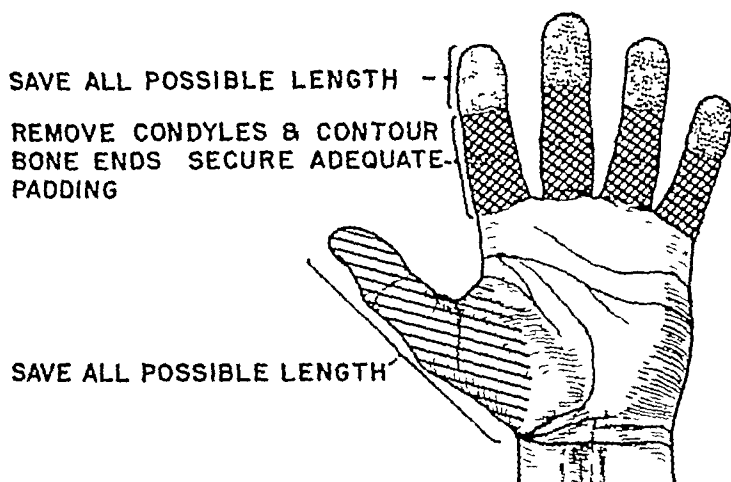


FIG 48—General rules for stump length in traumatic amputations

concern himself with how long the stumps of the remaining digits are (Fig 48) In general, the distal phalanx should be saved if possible, thus preserving the insertion of the profundus tendon and making the finger much more mobile and much stronger than it would be if the distal joint and the profundus tendon were sacrificed The only exception to this rule is in an injury which involves the distal joint with loss of the insertion of the extensor tendon In these circumstances a mallet deformity will result and no usefulness is gained by preserving the distal phalanx as a short stump Treatment of this complication is described in the chapter on Tendon and Muscle Injuries

Any part of the middle phalanx is valuable except the distal condyles, and these should be removed The proximal phalanx is valuable in many occupations and should not be sacrificed as a primary procedure If it is that of the index finger and the workman subsequently complains about

it, the stump may be removed and the metacarpal head beveled for appearances, but usually no appreciable increase in function is obtained by this maneuver

METACARPAL AND CARPAL AMPUTATIONS

METACARPAL AMPUTATIONS—A metacarpal amputation as a rule should not be done as an emergency procedure If a traumatic amputation occurs through the thumb metacarpal, what is left of this bone should be covered by local flaps, skin grafts or a pedicle from the abdomen Operation may be done later to lengthen the thumb by deepening the web or building out the stump The metacarpals of the fingers likewise should rarely be sacrificed primarily The metacarpals of the index finger and little finger add materially to the breadth of the palm, and if the palm is narrowed by their removal there will be less strength in handling of tools such as hammers and wrenches Removal of the metacarpals of the long and ring finger may produce serious disability When amputation is carried out proximal to the transverse metacarpal ligament, the adjacent metacarpals rotate and the fingers will then cross or deviate away from each other when flexed Slocum describes several procedures to overcome such defects However, none is completely successful A simple procedure is to amputate the whole metacarpal (Fig 49) This narrows the palm and partially corrects the deformity The more complicated procedures include transplanting the little finger to the ring finger position, transplanting the index finger to the middle finger position, transplanting a metatarsal to substitute for the amputated metacarpal and transplanting a proximal phalanx of a finger to fill the metacarpal defect If the thumb is short and a stub of the index finger is present, considerable increase in grip can be obtained by sacrificing the index metacarpal and deepening the thumb cleft (Fig 50)

Amputation of the second or fifth metacarpal is sometimes carried out for cosmetic reasons but narrowing of the palm results in some loss of strength Defects along the ulnar border of the hand require padding, either by a small flap applied from the abdomen or by excision of the fifth metacarpal so that the tough palmar skin can be brought around the ulnar border of the palm and a dorsal scar produced

Amputation through more than one metacarpal may produce severe disability If an unapposed thumb is left, the hand has almost no function (Fig 51) Many of these tragedies could be avoided by use of correct treatment measures The primary objectives are always to preserve pinch and grasp and, if possible, to give breadth to the palm and some sort of

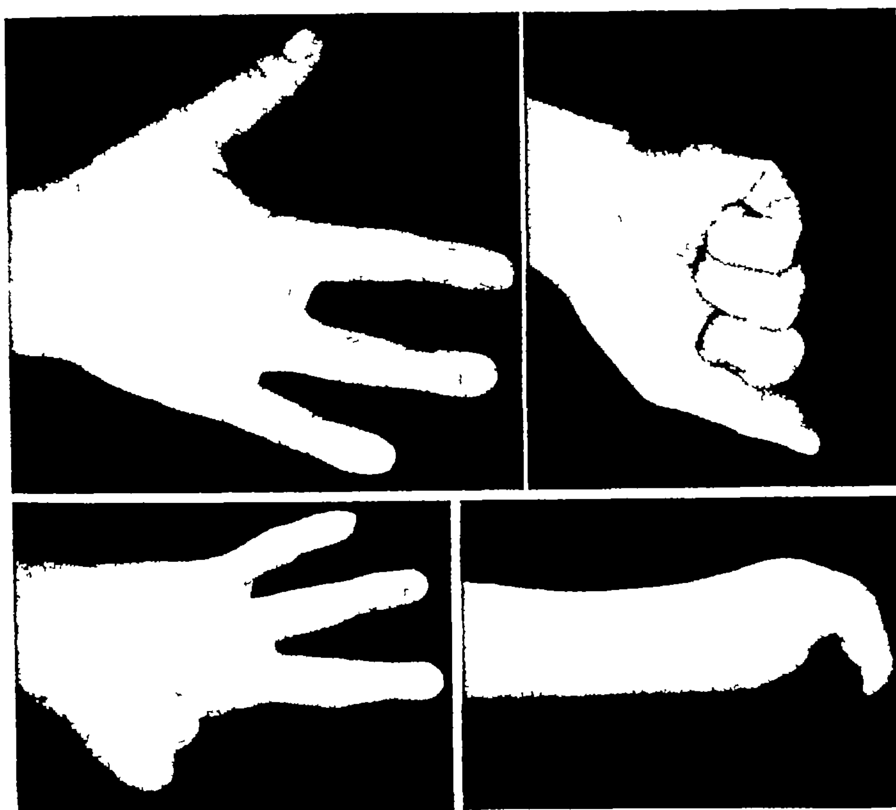


FIG 49 *(above)*—Amputation of entire third ray This hand has good appearance and function but lacks strength

FIG 50 *(below left)*—Amputation through radial side of hand (electric fan injury), short thumb stump allows some pinch and grasp Index metacarpal was removed and web deepened to improve grip

FIG 51 *(below right)*—Hand of child, aged 8, four years after injury from exploding dynamite cap Only function remaining is hook with badly damaged thumb

cleft between thumb and digits Very often in a primary operation little can be done except to try to get what is left of the hand covered with skin, using skin grafts if necessary Later some reconstructive procedure can be carried out to produce the necessary cleft and to hinge the bones toward each other and provide them with power

Treatment by type of injury—The types of injuries producing traumatic amputations of the metacarpals fall into three general groups oblique through the ulnar side of the hand, transverse, and oblique through the radial side of the hand

When *the injury is oblique through the ulnar side* of the hand, the ring and little fingers are gone, together with their metacarpals, but the thumb, index and long fingers may be preserved In this situation, the

pinch and grasp function of the hand is still present and the principal aim is to cover the ulnar border of the hand adequately This is sometimes accomplished only at the expense of further narrowing of the hand by removing a little extra from the metacarpals and fashioning flaps from the remaining skin on the palm and dorsum Usually some of the carpus will also have been sacrificed In these cases there are apt to be pronounced ulnar nerve irritation and causalgic phenomena Experience would indicate that much superior results could be obtained by closing the wounds primarily with a skin graft and replacing the skin graft by an abdominal pedicle at the earliest possible moment (Fig 52) The more experienced operator may choose to use a primary flap



FIG 52 —Hand caught in ice grinding machine, with loss of index and little fingers and severe ulnar neuritis. Good function obtained by secondary tendon and nerve repair and application of flap

When the *original traumatic amputation is transverse,* the middle three metacarpal heads are usually missing and the thumb and little finger are shortened to the extent of one or more segments (Fig 53) This is one of the most disabling of all hand injuries Healing of such a wound is usually poor, and little if any function remains except for using the palm of the hand as a pusher Sometimes a poor type of pincher develops between the stump of the thumb and the little finger Every possible means should be used to secure primary healing without sacrificing any digital length Here again skin grafts are valuable and a primary pedicle may be indicated The patient should then be given a trial at using what is left of the hand before reconstructive procedures are undertaken, since whatever is done will not be of much benefit Later a rotatory osteotomy of the fifth metacarpal may produce better pinch

If pinch is present and sensation is about normal, a hand can be obtained which is infinitely better than a prosthesis When painless, a remarkably useful member may be obtained (Fig 54)

The third type of amputation through the metacarpals, in which the

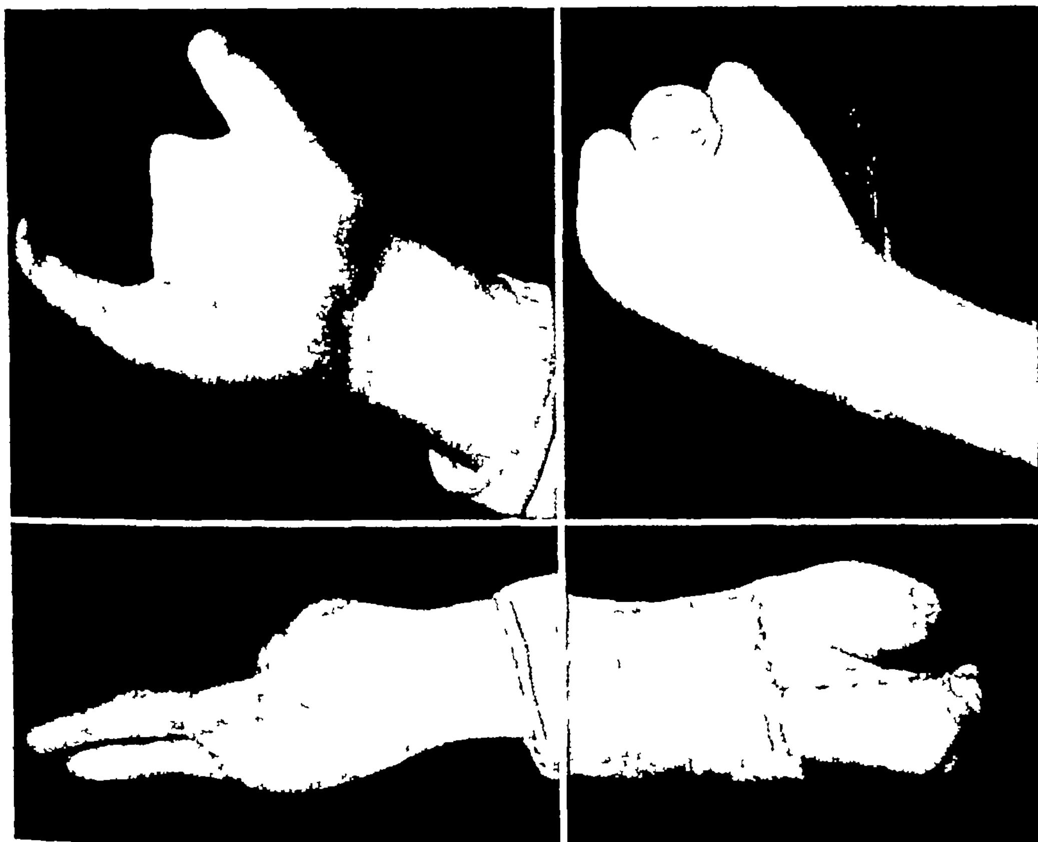


FIG 53 *(above left)* —Traumatic amputation of index, long and ring fingers and one-half the thumb (sawmill injury) Infection with further loss of tissue followed primary repair Skin grafting and removal of portion of the metacarpals resulted in pincher

FIG 54 *(above right)* —Shortest useful phalangeal amputation (caused by planer accident) Thumb web has been deepened to give pincher action

FIG 55 *(below left)* —First three metacarpals amputated when hand was caught in gears Pinch, hook and grasp preserved but weak

FIG 56 *(below right)* —Loss of digits and metacarpal heads in hand mangled by edger Remaining metacarpals were too short to phalangize adequately Though only flipper action and slight pincher function remained, result was far better than a forearm amputation

thumb, index and middle fingers as well as their metacarpals are lost, results in a hand which has only hooking action from the fingers and a little feeble pinch between the fingers If any of the thenar eminence can be preserved, the fingers will have something to oppose to and some grasp will be possible (Fig 55) Here again, everything should be done to pre-

serve what is left, either by skin grafting or by primary flap procedure, and no reconstruction should be carried out until after the patient has had a chance to try the hand to see what bothers him the most Later if the stump of the thumb is present, the web can be deepened to improve grasp

CARPAL AMPUTATIONS—Even if all the metacarpals are amputated through their base, a useful flipper type of paw can be salvaged and is better than a wrist or forearm amputation (Fig 56) Slocum believes that a disarticulation through the wrist or preservation of a portion of the carpus is preferable to a forearm amputation

PROSTHESES

Prostheses for the upper limb are not nearly as satisfactory as those for the leg The reason is that proprioception in the leg is a matter principally of weight bearing, and this can be transmitted through the wooden leg to the stump In the upper extremity, proprioception is a question of touch of a much finer nature Even though mechanical devices have been perfected which enable the wearer to pick up comparatively large or small objects, not much is gained because of the awkwardness in handling The only upper arm prosthesis which is universally accepted is a hook This device corresponds to the leg prosthesis in that it allows push and pull, with these sensations transmitted to the stump The workman who has a hook or some similar gadget with which he can fasten his forearm to a shovel or other tool uses the extremity for simple movements and does all the fine maneuvers with his uninjured extremity Cineplastic muscle motors for arm prostheses have been used at Walter Reed Hospital Experience with them would indicate the superiority of this method over the conventional type of prosthesis

Krunkenberg's amputation and the amputation devised by R H Alldredge to make a bifid hand from the stumps of metacarpals* are often acceptable only to bilateral amputees For one extremity only, the increased function allowed is not great and the cosmetic effect may be embarrassing or annoying to the patient

*A satisfactory method of making a functioning cleft in the palm is described in Chapter 14

CHAPTER FIVE

Burns

THE HANDS and the face, being exposed, are the most frequently burned areas of the body Hands are also used to put out fire elsewhere on the body or to push away or to grasp hot objects, and thus one of the most vulnerable parts of the body is most often damaged A small, deep burn of the body is not nearly as serious as one of the hand

ETIOLOGY

Of the various agents which may produce burns, those causing their effect by heat are the most hazardous, although various chemicals, such as caustics and acids, may produce quite serious injuries Burns produced by electricity or friction are probably the worst Those caused by hot ashes from which the person cannot extricate himself are also very severe. Flame burns are always serious In immersion in hot liquids, the degree of the burn depends on the boiling point of the liquid and the length of time of immersion or exposure Welders and those working around foundries often sustain small, deep burns from molten metal and these are usually crippling in their effect Flammable liquids such as gasoline produce their effect not only by heat but by extraction of oil from the skin

The hand is not particularly sensitive to actinic rays because it is hardened by daily exposure, but it may be seriously damaged from the radiation of x-rays This particular type of burn produces its ill effects by interference with the circulation in the digit as well as by directly causing atrophy of the skin

PATHOLOGY

Burns were formerly classified according to six different degrees, starting with erythema of the skin and ending with destruction of the bone The modern concept is to use only two classes superficial (partial thickness) and deep (full thickness) If the skin is destroyed, the burn is deep, if it is capable of healing without scarring, the burn is superficial The more serious superficial burns (deep partial thickness burns or what were formerly called deep second degree burns) may be capable of healing spontaneously from the epithelium of the deep structures of the skin, although not without considerable scarring and loss of function In the hand these should be classed as deep burns and treated as such

The pathogenesis of all types of burns short of complete charring is a capillary response to thermal injury which may result in either capillary engorgement, loss of fluid through the capillaries or complete thrombosis of the capillaries, depending on the severity of the burn and the proximity of the capillaries to the burned area There is an outpouring of interstitial fluid with the production of edema, and loss of fluid may occur from the wound itself Edema develops rapidly during the first few hours after a burn and gradually subsides after 36–48 hours when the pressure within the tissues overcomes the pressure of extravasation In full thickness burns the hard eschar present may mask the edema However, edema is present in the tissues inside the extremity, and in the hand the proteins in this fluid may cause much stiffness later

PARTIAL THICKNESS BURN —Microscopically, a partial thickness burn which amounts to nothing more than erythema shows little aside from engorgement of the blood vessels In a few days this engorgement subsides and the appearance returns to normal The inflammatory response in the skin produced by a blistering burn is characterized by an outpouring of lymph within the epidermis accompanied by hyperemia and a certain amount of cellular response in the dermis When the burn is superficial, the blister lifts off a few of the outer layers of the stratified squamous epithelium This type of burn is not a scar producer, although at times there may be changes in the pigment-forming cells, especially in dark-skinned persons, so that a brown spot later identifies the burned area If the burn is somewhat deeper, the blister may lift off all the squamous layer down to the rete pegs and cause considerable inflammatory response in the underlying corium Such skin will heal without contracture but with definite changes in appearance, there frequently being pigmentary changes with a certain amount of smoothness and atrophy

without loss of hair or sweat glands In a burn a little deeper, a certain amount of scarring occurs with mild contracture, giving rise to a pigskin appearance of the healed skin This type of reaction is less apt to occur on the hands than on the abdomen, upper arm or thigh If the entire epidermis is sloughed off, regeneration of epithelium takes place from the glandular elements and hair follicles which are still present in the deeper layers The resulting skin is thin, shiny and poor in quality, and the scar beneath it always contracts, drawing in the surrounding tissues When this amount of destruction is adjacent to a joint, motion in the joint stimulates the scar tissue to keloid formation and further scarring and contracture result This is the reason keloid formation is so common on the hand

FULL THICKNESS BURN —In a full thickness burn the entire thickness of the skin is immediately charred or boiled to eschar or soon sloughs away due to the inflammatory reaction that takes place beneath the burn Healing then cannot be accomplished by any remaining skin elements When the dead skin sloughs or is removed by the surgeon, an open wound is left which fills with granulations and contracts, skinning over eventually by ingrowth of epithelium from its edges The resulting skin, like that of a deep partial thickness burn, is thin, shiny and atrophic The tissue immediately beneath it is scar tissue and will not stand wear or abuse Scarring that is present on the trunk is inconvenient chiefly because of the appearance and the lack of good sensation Scarring on an extremity draws upon the joints and, if circumferential, may interfere with circulation, on the hand, its results are crippling

The skin on the back of the hand stretches approximately one-fourth its length when all the joints are flexed, and its elasticity makes it lie smooth even when the joints are extended After a partial burn, this elasticity is lost and there is a feeling of tightness when the hand is clenched, and frequently there is actual restriction of motion In deep burns the mechanics of the whole hand are upset During healing the joints are drawn into subluxated positions and the mechanism of the tendons is drawn out of balance

PATTERNS —Burns of the hand tend to fall into certain predictable patterns The gloved hand, suddenly exposed to hot asphalt, presents a circumferential burn of the wrist, usually with complete destruction of the skin in this area and often with a burn of less severe degree of the forearm and hand The hand exposed to flames usually has deep partial and full thickness burns of the dorsum with, at times, roasting of the finger joints and loss of extensor tendons in this region but without com-

parable damage on the palm. Children more frequently burn the palms of their hands, in adults the dorsum is more often burned.

The electrical burn often causes far more extensive destruction of the deep structures than would appear from the surface. Nerves and tendons are destroyed and the palm is usually deeply scarred. The digits become atrophic and functionless and the hand is drawn into grotesquely deformed positions.

In deep burns of the dorsum, keloid formation produces a webbing of the interdigital clefts, and the proximal finger joints are drawn into hyperextension. The central slip of the extensor tendon over the middle finger joints is lost. These joints are drawn into flexion, and clawing of the hand follows. Deep burns of the front of the hand cause contractures of the fingers, and the thumb may be drawn down into an adducted and cramped position. A hand deeply burned in infancy or childhood may, with growth, become drawn into a grotesque pawlike position unless multiple procedures are undertaken for correction.

DIAGNOSIS

Ascertaining the thermal agent that produced the burn as well as the duration of exposure will aid the surgeon materially in judging the severity of the burn. The circumstances of the accident, if known, may enable him to suspect or rule out a concomitant head injury, internal hemorrhage or other trauma in an unconscious patient.

Judging the depth of a burn is a faculty which can only be learned by experience. In cases in which charring occurs or the skin is dead white or the blood in the superficial vessels can be seen to be coagulated, there should be no doubt in diagnosis. Vesiculation occurring almost immediately after the injury, with thick-walled blisters developing some time later, or simply an erythema which blisters later indicates a less severe burn. The presence or absence of pain is also a fairly reliable criterion, since pain is absent when the skin is entirely destroyed.

Shock may not be obvious a short time after the burn, if judged by the usual pulse and blood pressure findings. In severe burns, shock always appears within a few hours and progresses at an accelerating rate unless vigorously treated.

TREATMENT

The literature on the treatment of burns constantly presents new methods which are in turn discarded for other new methods or old ones which

are resurrected In a relatively short time the local treatment of burns has passed through a number of phases, and these are summarized in Table 1

TABLE 1 —TREATMENT OF BURNS

	COAGULUM METHODS	
Acids		
Dorrence, G M	Acetic acid	1922
Neate, N M	Picric acid	1924
Thayer, F K	Butesin picrate	1924
Davidson, E C	Tannic acid	1925
Bettman, A G	Tannic acid–silver nitrate	1935
Coan, G L	Ferric chloride	1935
Dyes		
Aldrich, R. H	Gentian violet	1933
Mummery, N H	Acriflavine	1933
Novikov, L E	Brilliant green	1934
Jens, J M	Mercurochrome	1936
Aldrich, R H	Triple dyes	1937
Exposure		
Amspacher, W H		1952
	DRESSING METHODS	
Oils and ointments		
McMullen, C. G	Ambrine	1917
Cohen, H	Paraffin	1921
Tomb, J W	Linimentum calcis-chlorinatae	1924
Bellet	Lanolin	1925
Cook, C. K.	Paraffin wax	1930
Hardin, P C	Cod liver oil	1941
Miscellaneous		
Horan, F P	Dichloramine T	1921
Davidov, P D	Ashes of wool	1933
Bunyan, J	Envelope method (Bunyan bags)	1940
Hudson, R. V	Coated fabrics	1941
Koch and Allen	Compression and elevation	1942
Levenson, S M	Closed plaster casts	1943
Reese, E C.	Sulfanilamide films	1945
———	Saline baths	
	Saline packs	
	Enzymes	

In the paragraphs to follow, the general rules to be observed are explicitly enumerated and the various agents are only alluded to without specific directions for use One should distinguish between methods and agents, the method employed being more important than the agent used

Underlying every method is an attempt to promote healing of the wound locally and to prevent the absorption of toxins and the disturbance of physiology which lead to shock and to death of the patient In the section on burn shock it will be seen that local treatment so far has not been found to influence burn shock materially The treatment of the burn

locally is a problem in wound healing A superficial burn involves only a partial thickness of the skin, if the physician protects what is left, the wound will heal A deep burn includes the entire thickness of the skin, nothing which is applied topically will bring the dead skin back to life, and removal of this burned area followed by skin grafting is mandatory The apparent success of some of the local methods noted in the table was due to the failure to distinguish between superficial and deep burns This was especially true when the various eschar methods were used in treatment of deep superficial burns

Partial Thickness Burns

When the deep partial thickness burn (deep second degree) heals under some form of therapy in which the healing process can be observed, it will be noted that after the skin has sloughed away, small gray dots of regenerating epithelium appear on the granulating surface This regenerating epithelium is derived from hair follicles and sweat glands Being multicentric in origin, the regenerating islands rapidly coalesce and soon cover the entire surface This process will always be observed to take place, provided the burn is not too deep and the regenerating epithelium is not destroyed by rough handling or secondary infection. A similar process takes place unobserved under the eschar method

ESCHAR METHOD —Eschar methods all share one fallacy in common tanning agents actually have some effect on live tissues and consequently make the burn deeper In the same way, infection occurring underneath an eschar may destroy what is left of the skin elements there Tannic acid, the most popular eschar producer, has been shown to produce liver damage *

The defects of all the eschar methods are magnified when applied to the hand The position of function is often lost, resulting in increasing stiffness, movement of the joints cracks the eschar, leading to infection beneath it, constriction produces circulatory changes, and definitive skin grafting is often delayed longer than necessary

EXPOSURE METHOD —Despite objections to the eschar method and its general abandonment, there has been a recent resurgence to a variation of this method, the so-called exposure method in the treatment of burns (Fig 57) In the exposure method the patient is given morphine and treated for shock with suitable colloid and electrolyte solutions Penicillin

* E I Evans finds moderate to severe hepatic damage in many patients not treated with tannic acid

and tetanus toxoid or antitoxin are given As soon as feasible, the patient is disrobed and the burn and adjacent area cleansed with soap and water or a detergent The burned surfaces are cleansed as gently as possible The patient is then placed in bed on clean sheets in such a position that the burned area can be exposed, immobilized and elevated The exudate produced by the burn generally becomes dry in about 12 hours and a hard protective crust forms within 48–72 hours. Antibiotic administration is continued until crust formation is complete and always for at least five days The crust separates in about 14 days in superficial burns and some time during the following week in deep partial thickness burns When the eschar is deeper, particularly on the hands, it should be removed after



FIG 57 —Localized partial and full thickness burn treated by exposure method

10–14 days and grafting carried out either immediately or after 48 hours of dressings †

The exposure method is not easy to use on extensive, deep, circumferential burns in which a large burn area would rest on the bedclothes

For ambulatory patients the exposure method is not always practical. Unless the burn is quite circumscribed, most of these patients are more comfortable if some form of occlusive dressing is used.

Burns of the hands are also best treated by pressure dressings Occasionally, when both hands are burned, the less burned hand is left exposed so the patient can feed himself

Treatment of burns complicating open fractures or extensive soft tissue damage by the open method is contraindicated

The exposure method is difficult to use in children It eliminates the

† The method described was used in over 200 cases at the Army Surgical Research Unit under the direction of Col William H Amspacher and was found particularly useful in treating burns of the face or of the hands and forearms

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Allen are 24 ply Cellucotton with fine mesh gauze on one side A single layer of fine mesh grease gauze is considered adequate

The hand should always be placed in the position of function (see Fig 22), keeping the thumb well away from the fingers, preserving both the transverse and vertical arches of the hand, extending the wrist slightly and flexing each joint of the digits slightly. This position is maintained by splinting, either with a Mason-Allen position-of-function splint or by placing a pile of gauze on the end of a board The compression dressing should not be tight, but it should be large and resilient and must properly

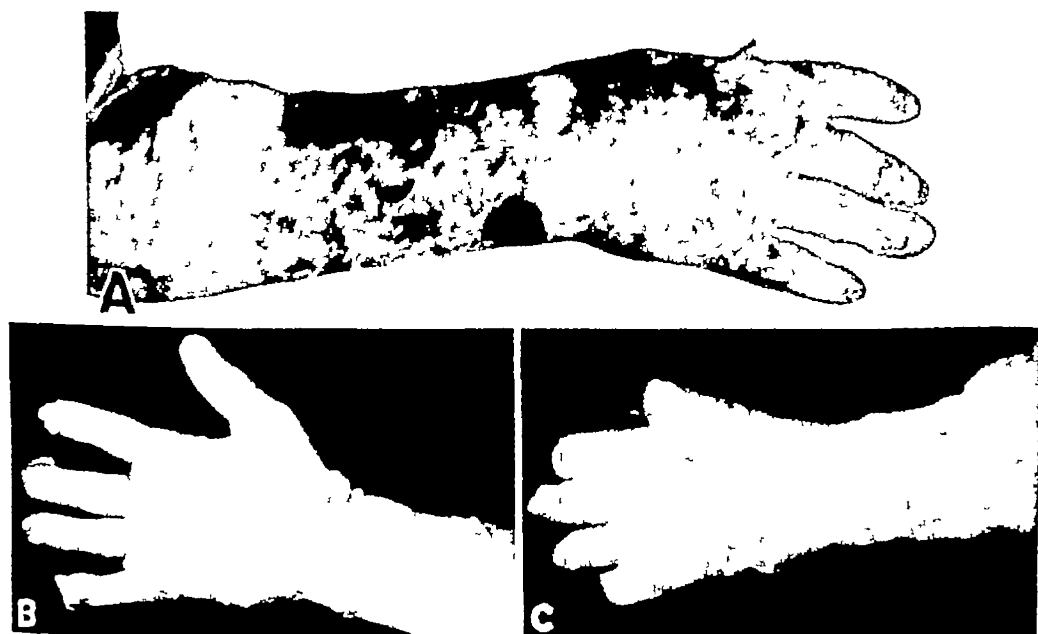


FIG 58—Extensive partial and full thickness burn treated by compression dressing technic *A*, appearance of hand *B*, fine mesh grease gauze applied *C*, compression over grease gauze with Kerlix A position-of-function splint was used to maintain this position

immobilize the part Elevation of the patient's hands when he is returned to bed should be routine

The use of a gauze impregnated with some chemical, antibiotic or other bactericidal preparation in dressing the burn is optional Antibiotics given parenterally will produce an ample concentration in the wound area once devitalized tissues are removed, and no particular advantage would therefore seem to be obtained by using them locally All patients with burns of major extent should be given either tetanus antitoxin or toxoid

AFTER-CARE—The first few days after a severe burn a patient may have a mild to moderate febrile reaction and a moderate leukocytosis These are not signs of infection per se but indicate a toxic reaction of

necessity of dressings but requires excellent nursing care and thorough understanding on the part of the patient, who must comprehend and co-operate

The treatment of burns by the exposure method is still *sub judice* but will probably find a place in the general over-all picture of burn therapy In the event of disaster, treating burns by the use of occlusive pressure dressings would create a problem in the supply of dressings

OCCLUSIVE DRESSING METHOD.—The occlusive dressing method became popular after the Coconut Grove fire of 1943. Burns of these patients were treated by the application of bland ointment, pressure and infrequent changes of dressings, and early wound healing and restoration of function resulted This method followed the technic introduced by Koch and Allen in 1942 The underlying principle is that injured tissues need rest and that elevation, compression and being kind to the tissues will be conducive to early healing

The patient is first treated for pain and shock as in any type of burn Morphine may be needed for pain, and fluids and blood should be given intravenously for shock Clothing and any emergency dressings are then removed in the operating theater, with light anesthesia being given as necessary * The arm is laid out on an armboard covered with a sterile sheet, and the surgeon carefully and gently cleanses the entire extremity, using a bland soap or detergent, removing detached epithelium and puncturing blisters † After cleansing and removal of rings, fine mesh gauze impregnated with a bland ointment is applied to the burned area The fingers are dressed individually Sterile dry gauze dressings and compression then is applied uniformly to the whole area

Special dressings are available with which each finger can easily be dressed separately in the position of function Surgitube impregnated with petrolatum is first applied to each digit The rest of the extremity is covered with fine mesh grease gauze Kerlix is then wound directly around the finger, the hand, the forearm, etc (Fig 58) For the hands and forearms, not much additional compression is necessary, the hand is placed on a position-of-function splint, wrapped with additional Kerlix and an Ace elastic bandage applied loosely Several one-piece burn dressings composed of compression material combined with a single layer of mesh gauze have been developed The dressings used by Koch, Mason and

* Harvey S Allen believed that anesthesia is inadvisable because of the possibility of shock

† Thomas W Stevenson believed that blisters should not be punctured and that dressings should be applied without debridement

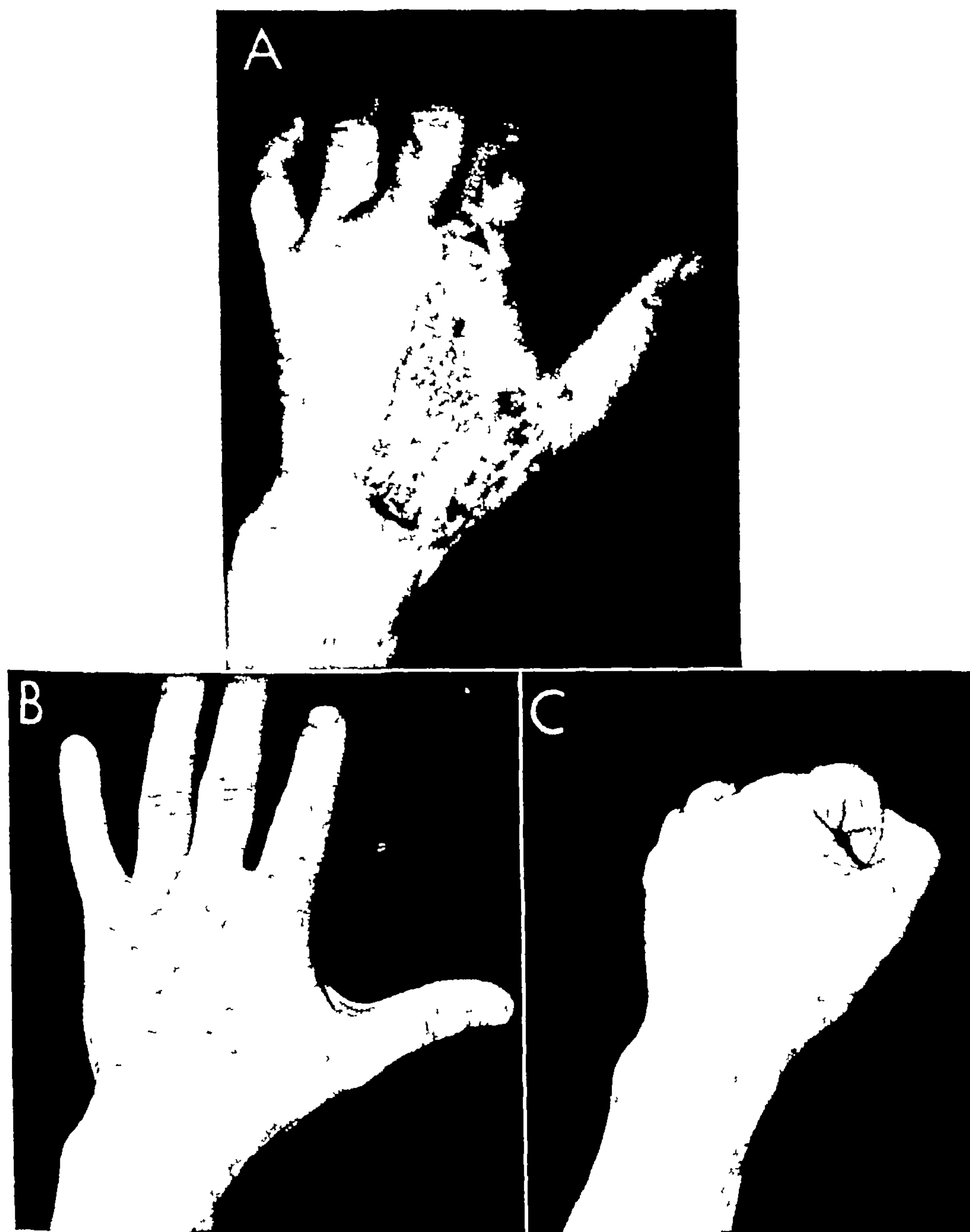


FIG 59—*A*, full thickness friction burn *B* and *C*, result after treatment by excision and immediate skin graft a few days after injury

the foreign protein type After a week the presence of fever, especially of the swinging type, should call for investigation of the burned area to see if suppuration is occurring Before antibiotic therapy was used, it was common to see an erythematoid reaction along the edge of a deep burn, which in severe cases would spread rapidly, giving the appearance of erysipelas Death frequently resulted With antibiotic therapy this complication is uncommon

In partial thickness burns spontaneous healing in 14–21 days should be the rule and for most areas of the body no further treatment is indicated For burns of the hand, the patient should be under observation during convalescence because pronounced stiffening of the joints may occur even with primary healing The hand should be exercised assiduously and the skin kept soft with lanolin Recurrent small blisters may have to be dressed, and any area of persistent granulation should be patch-grafted Eventually, unless the patient is a keloid former or the burn was deeper than was originally apparent so that scarring and contractures develop, there should be full return of function

FULL THICKNESS BURNS

IMMEDIATE GRAFTING—The only adequate treatment of full thickness burns is to prepare the wound and to cover it with skin grafts at the earliest possible time Immediate grafting of burned areas theoretically should be ideal In circumscribed deep burns of the hand, such as those caused by hot metal, friction or phosphorus, it may be advantageous to excise the burned area and apply split thickness grafts to the underlying viable tissue within a few hours after the burn occurs Immediate excision is indicated especially when the extent of the full thickness burn is readily identified and the total extent of the burn does not exceed 20 per cent of body surface (Fig 59)

Under general anesthesia, the extremity is prepared as for a routine surgical procedure and the local burn is completely excised As bleeding aids in determining whether tissue is viable or not, no tourniquet is used A layer of edema is often present between burned tissue and normal tissue The subcutaneous fat should usually be sacrificed After removal of all doubtful tissue, a split thickness skin graft is applied

Although this method would appear to be ideal in localized burns of the hand, in actual practice it has many limitations (1) Frequently small, deep burns are encountered in which not only skin but the underlying tissues are severely compromised, with tendons, nerves, joints or bone

After the excision of devitalized tissue, the wound is occasionally grafted immediately This method is best used by those experienced in the treatment of burns or in plastic surgery Usually dressings are applied and grafting postponed until healthy granulations appear Much bleeding after excision of the slough makes the area unsuitable for grafting If the burn is very deep, some nonviable tissue may remain In very deep burns debridement should be exceedingly conservative, only tissues that are obviously devitalized being removed Removal of nerves or tendons should be avoided as long as possible, the latter usually sequestrate in one piece during the third week A few more days devoted to compression dressings or use of simple saline packs prevents failure of skin grafting The same type of immobilization and fine mesh gauze is employed as was used in the original dressings, care being taken to maintain the position of function

For an uncomplicated burn of an extremity (one in which there is no destruction of muscle, tendon or bone) it should be possible to excise or dissolve the eschar, prepare the wound and have the skin grafting done before the end of the third week In the more complicated burns, the extent of dead tissue will be painfully evident by the end of the third week. Muscle tissue will now be approximately the consistency of firm white fish flesh, tendons will be either a dull dead-white or swollen and yellowish and easily pulled apart, bony structures when attacked with a rongeur will be a dull brownish color and will not bleed, nerves will be swollen and frayed but may still be viable By this time it should be possible to excise cleanly all nonviable tissues The use of intermittent saline dressings plus repeated superficial debridement by the surgeon or the nurse will remove any remaining nonviable tissue, and within a few days the arrival of firm, pink, shiny granulations together with a slight ingrowth of skin from the wound edges will announce that the wound is ready for grafting In extensive burns it is better to proceed in easy stages than to try to do too much However, it must be emphasized that early removal of the burn slough and early grafting give a higher percentage of closure, while the patient's general nutrition and healing potentials are maintained Late grafting never gives as good results The use of *postmortem homografts* should always be considered in very extensive burns J Barrett Brown was able to save patients with burn areas up to 70 per cent with this method Thin split grafts taken from a fresh cadaver under sterile conditions may be stored by folding them in gauze moistened with a saline antibiotic solution Placed in sterile jars they may be kept 21 days in an ordinary refrigerator (3–5 degrees C)

being exposed after debridement For these cases, proper care requires the application of a pedicle or flap, since skin grafts take poorly over such structures (2) Unless the burned surface is solitary or suitably located, the application of an immediate flap may not be possible (3) Rather fine judgment is needed to determine just what constitutes burned tissue Even a pathologist may not be able to decide whether or not a given layer is viable Usually after immediate excision a waiting period of two to five days to obtain granulation buds will enhance the take of the graft

DELAYED GRAFTING—Delayed grafting preceded by intermittent dressings plus debridement is the most reliable method of treatment for full thickness burns In most hands that are severely burned, there are areas of partial thickness destruction accompanying areas of full thickness destruction Therefore, the proper procedure is to allow enough time for the areas with partial thickness burns to heal and then proceed with grafting of the full thickness burn areas

To allow the burn slough to become infected and separate by further sloughing is unnecessary and only inflicts further injury to the hand The removal of the slough may be hurried along by excision or by the use of certain enzymatic agents such as pyruvic acid, streptokinase, streptodornase, collagenase or Zinax Many authorities question whether these agents are any better than saline packs They are expensive Chemical debridement works best on moist sloughs and is useless on deep structures covered with a dry eschar unless this is "cross hatched"

The *first redressing* of any serious burn of an extremity should be done under aseptic conditions, preferably during the second week The dressings by this time are often saturated and a typical odor is present The presence of an odor does not mean that the burn is infected

In partial thickness burns in a co-operative patient, it is not necessary to administer an anesthetic for redressing It is not uncommon at the first redressing to have the entire epithelium separate, together with the fingernails, without the burn requiring skin grafts In full thickness burns removal of the slough is more difficult* and requires general anesthesia, when it is removed, the palmar fat on the volar surface of the hand and the extensor tendons on the dorsum are exposed Tendons are also apt to be exposed above the wrist in the forearm Tendons do not withstand exposure well and usually slough later For this reason some authorities recommend application of an immediate skin dressing at the time of first debridement, usually five to eight days after the burn This may prevent the small joints and tendons from becoming necrotic

* M L Mason excises slough with the electric dermatome

to calculate the amount of fluid necessary to counteract burn shock, using laboratory determinations of the total protein and the hematocrit as well as the standard blood count and sedimentation rate None of these methods has any advantage over the more practical one of calculating the amount of fluid needed by the size of the area burned Estimation of the area burned is easily made by reference to Figure 60 The formula for fluid replacement is then as follows colloid solutions, 1 cc per kilogram for every per cent of body burned, electrolytes to equal colloids, 2,000–3,000 cc. water with glucose to replace insensible losses This total amount

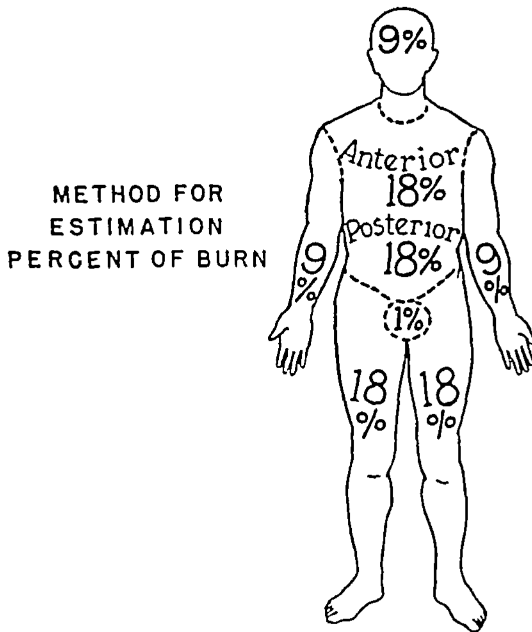


FIG 60 —Rule of nines to estimate per cent of body burned (Figs 60 and 61 from Amspacher, W H, and Reiss, E, in Bowers, W F *Surgery of Trauma* [Philadelphia J B Lippincott Company, 1953], used by permission)

is given during the first 24 hours, divided so that one-half is administered in the first eight hours and one-fourth in each successive eight hour period Not more than 200 cc per hour should be given by mouth During the second 24 hours the amount is reduced 50 per cent The approximate fluid requirements in a 30 per cent burn are given in Figure 61

The colloid solution which was formerly most commonly used was plasma Homologous serum jaundice has become so widespread from use of plasma that even after irradiation its use is not acceptable except in emergency * Whole blood is indicated in treating any burn and the pres-

* According to recent publications, plasma which has been stored for 6 months may be free from the viruses which cause hepatitis

The technic of grafting burned areas is described in Chapter 6 Besides the local preparation of the burned area, the care of the patient as a whole may present a complicated problem

BURN SHOCK

While the aforementioned local changes are occurring in the area exposed to thermal damage, the effects of these changes are manifest throughout the body in the form of alterations in the physiology of circulating fluids which may produce the condition known as burn shock

The important factors which are known to be influential in the production of burn shock are *capillary injury, vasodilatation in the wound* and *red cell destruction.* The injured capillaries pour out a fluid which is like plasma but contains less protein and relatively more albumin and less globulin This fluid is forced into the surrounding area as well as into the burned tissues A relatively high loss of electrolytes and albumin in this edema fluid results in a higher concentration of protein in the remaining circulatory blood Extracellular fluid will be drawn from the unburned portions of the body and, if the burn is not extensive, blood volume will be maintained at an adequate level

Red cell destruction is due to the direct burning of some cells, to a weakening of the structure of others, so that they subsequently become hemolyzed, and to capillary dilatation with stagnation of cells in capillaries resulting in sludged blood

It will be seen that the two factors of capillary injury and red cell destruction are not interdependent and that, depending on whether more plasma or more red cells are lost, a variable degree of hemoconcentration or hemodilution may be produced (indicated by a relatively high or low hematocrit reading) without giving any indication of the total loss of circulatory fluids

The known factor which can be combated in the treatment of burn shock is the loss of circulatory fluids in the form of plasma, electrolytes and red cells, the amount of this loss being dependent on the extent and depth of the burn Vasodilatation and increased capillary permeability remain little understood factors in the pathologic physiology of burns Consequently no satisfactory approach to their therapy has been made The various hormones, including corticotropin, cortisone and adrenal cortical extracts, have all proved to be ineffective, and no local treatment has been shown to reduce materially the total amount of fluid escaping from the circulation

Fluid requirements—A number of different methods have been devised

hemoglobin and corrective measures should be taken if they are found to be below normal. A diet containing 2 or 3 Gm of protein per kilogram of body weight and supplementary vitamins should be given, and anemia corrected by repeated small transfusions

COMPLICATIONS

Deep burns of the dorsum of the hand are apt to destroy the extensor tendons, especially those over the middle joints of the fingers The middle joint then flexes and the end joint becomes hyperextended Even though the tendons may appear to be undamaged after the skin separates, they are often dead and will neither cover with granulations nor support a skin graft When bones as well as tendons are burned, a difficult problem is presented Here, conservatism is worth while because the interphalangeal joints are almost certain to be stiff regardless of treatment Usually the only means of eventual restoration of function is to restore motion in the metacarpophalangeal joints, with the finger joints each ankylosed in about 45 degrees of flexion Whenever a debridement is done in these cases, the temptation is to remove what appears to be dead bone If this is done and either of the proximal phalanges is sacrificed, the finger is rendered permanently useless Conservatism here is well worth while since the cortex on the dorsal side of the phalanx may separate and leave a functioning bone on the volar side If, after the hand heals, some of the fingers have satisfactory function and one is hopelessly stiffened, this one can be amputated This usually involves the fifth finger which, when left, is nothing but a stiff, bony hook

In deep burns of the dorsum of the fingers that require skin grafting, the central tendon slip over the proximal interphalangeal joint is usually found to have been destroyed This is the one situation in which the surgeon may improve the function of the hand by transferring the lateral bands of the extensor mechanism onto the dorsum of the joint The bands are freed laterally throughout most of their length and are then shifted to the top of the joint and fastened together with a few interrupted sutures of no 38 stainless steel wire The entire dorsum of the fingers is covered with a skin graft in the routine manner The end result of this procedure (Fig 62) will be better than the clawing of the hand which would result from subluxation of these tendons

The biggest problem in healing in a burn of the hand is prevention of stiffness and contractures Although children do not need physical therapy, it is important in adults, and any person over 30 should have

ence of a high hematocrit value is not a contraindication Hemoglobinuria is a sign of massive red cell destruction and calls for blood specifically. Ringer's solution is preferred to isotonic saline for electrolyte replacement

It is better to anticipate burn shock than to wait for its arrival Burn shock may be anticipated whenever the area is larger than the exposed hands and face As soon as the patient is admitted, venipuncture should be performed, a blood specimen obtained for cross matching, and intravenous fluids started Thirst, restlessness, disorientation and oliguria precede a rise in pulse rate or a fall in blood pressure An adequate

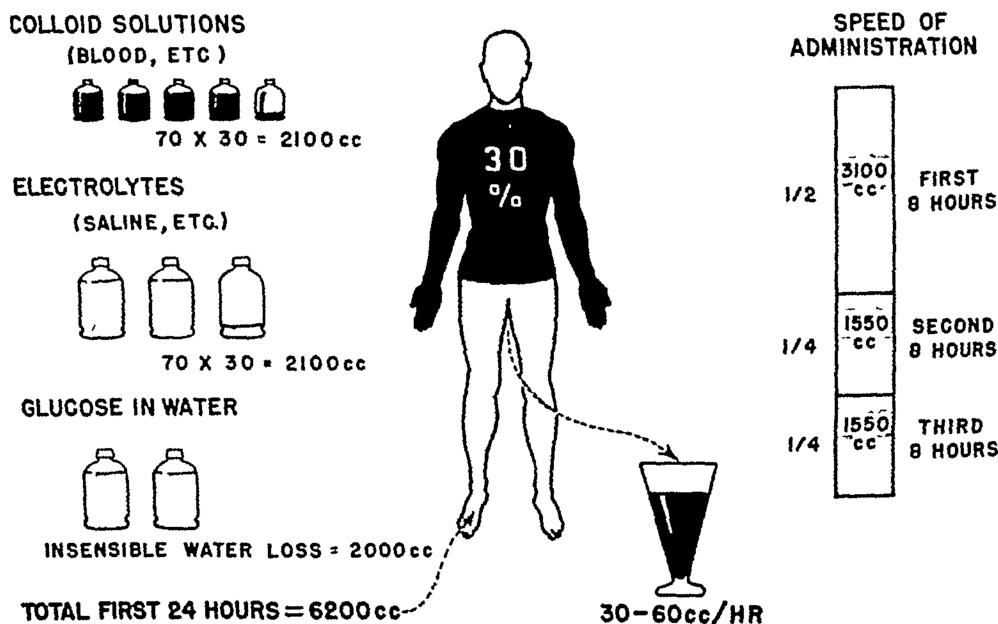


FIG 61—Fluid requirements for 30 per cent burn (upper extremities and anterior trunk), 70 kilo man

urinary output is, therefore, a reliable sign that shock is being avoided At least 1 oz of urine an hour should be excreted unless the kidneys are severely damaged An insufficient urinary output is more apt to be due to inadequate intake of fluids than to kidney damage Usually a rapid infusion will result in an increase in urinary output within one-half hour, failure for this to occur indicates kidney damage An indwelling catheter should be used and hourly urine flow recorded

Protein deficiency—Closely related to the treatment of shock are the secondary anemia, protein deficiency and nitrogen imbalance which appear the third or fourth day after the initial burn shock Laboratory studies should be made to determine the levels of plasma protein and

slides along a paved street Thus, other parts of the body are also involved Either of these conditions is actually an abrasion, without much thermal burn In grindstone burns the loss of tissue is almost always the full thickness of the skin and frequently deeper Grindstone burns should be treated by immediate debridement of the wound, with an economical excision of any doubtful tissue, and application of a split thickness skin graft Even if bone is exposed in the depths of the wound, the wound will usually heal (Fig 63). Treatment by simple dressings is not advisable since prolonged use of dressings is necessary, infection is inevitable and painful scarring results

In brush burns and especially in the type sustained in falls from a

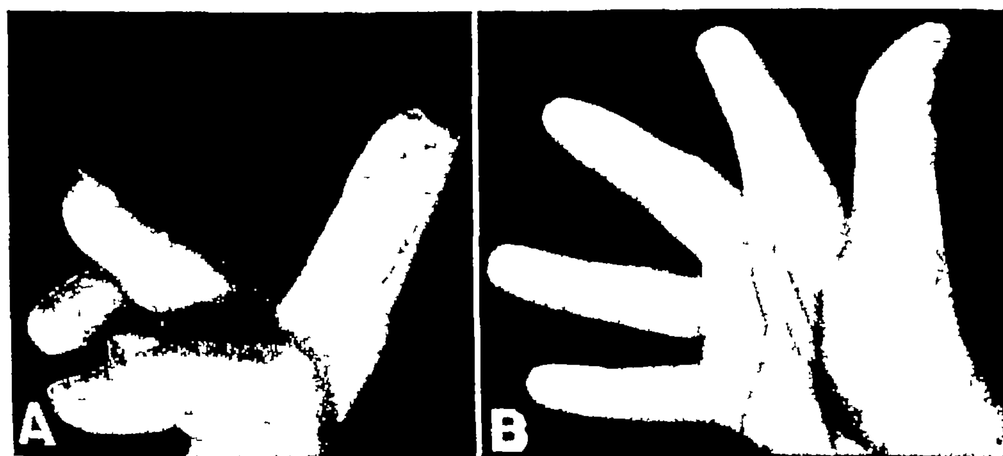


FIG 63—Loss of soft tissues and part of bone from side of long finger (grindstone injury) treated by immediate skin graft *A*, first redressing *B*, one month later

speeding vehicle, the object of treatment is to render the tissues clean, preventing the tattooing which will inevitably follow if dirt is left in the interstices of the skin during the healing process These patients should be given a general anesthetic as early as conditions permit and the involved areas scrubbed with soap and water and a stiff-bristled brush The wounds are then dressed with petrolatum gauze and pressure and treated postoperatively exactly as a thermal burn There is rarely a complete loss of skin, and much less scarring will occur if every bit of dirt is removed

The most severe burns encountered are a type of friction burn occurring when the hand becomes involved in a hot roller press If the hand survives and is not amputated, treatment may be carried out as described on page 115 When bone is uncovered, the formation of granulation tissue can be encouraged by making multiple drill holes in the bone

ELECTRICAL BURNS—The growing use of electricity has increased

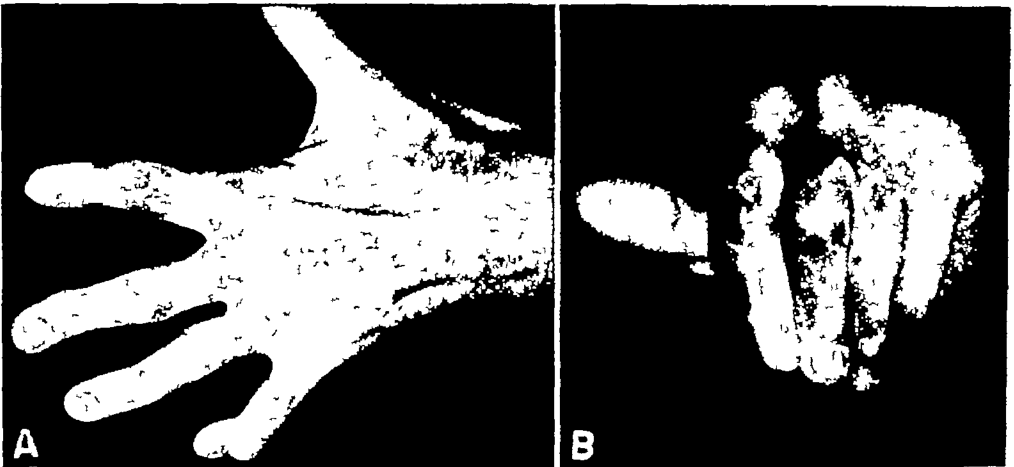


FIG 62 —Mangle injury in woman, 55, resulted in third degree burns of dorsum of fingers with loss of extensor tendons over middle joints After three weeks of treatment by dressing, skin grafting was done (by Dr Charles E Gurney), the lateral bands being transferred to the dorsum at this time *A* and *B*, considerable function was obtained, the patient is able to play piano, do housework, etc

motion started at least within two weeks After the skin contracts there is secondary contracture of the muscles and joints This leads to a hopeless situation which could have been prevented by proper early skin grafting Unfortunately, there is a tendency to neglect the hand when the patient has extensive burns elsewhere on the body

OTHER TYPES OF BURNS

MANGLE BURNS —These burns are due to a combined crushing effect from rollers and the thermal effect from the hot plate The palmar surface is more often affected, and as these burns are quite deep and are often complicated by infection the result is a severely crippled hand

Treatment —To obtain the best results several operations are usually necessary As the exact depth of these burns cannot be determined accurately, primary treatment should consist of occlusive dressings Primary debridement can be done at the end of about seven days, and thin skin grafts are applied as soon as possible after this After several months the thin grafts are removed and thick dermatome grafts applied Z-plasty and other types of plastic procedures may be necessary later

FRICTION BURNS —Two types of friction burns occur In one, the hand is pressed against a rapidly moving wheel or grindstone, in the other, the grinding object is stationary and the hand is moving The second type usually results when the patient is thrown from a speeding vehicle and

Kenneth Lewis of Chicago, who made an exhaustive report on this subject in 1956, recommends postponing debridement in these injuries, since life is not endangered and unnecessary surgery is thus avoided Definitive care consists of excision of the entire necrotic area and covering with a graft of indicated tissues My own experience with attempts to save doubtful deep structures by covering with flaps before the wounds became stabilized proved disappointing, and I now proceed with repeated debridements, skin grafting in stages, and pedicle grafts after as much healing as possible with split grafts The prognosis in most electrical burns must be guarded

RADIATION BURNS —These injuries were common in the earlier days of x-ray diagnosis and treatment but should be rare now A new type of radiation burn occurs in industry to the worker who exposes his hands while working a fluoroscope or x-ray machine and to others who work with radioactive materials If severe, the signs may appear within several weeks of the injury There is reddening of the skin followed by blistering and superficial ulceration Despite dressings, the ulceration deepens and becomes painful Indolent ulcers may expose tendons in the depths of the wound In severe cases the involved area should be excised and the skin and subcutaneous tissue replaced by the pedicle method In milder cases a radiodermatitis develops after a number of months or years Telangiectasias, smoothening and drying of the skin are first to appear, later hyperkeratosis occurs and may be associated with development of carcinoma after 10 or 15 years Whenever radiation burn is followed by radiation dermatitis, the skin should be replaced by grafting In burns from radioactive substances, early skin grafting is mandatory.

FROSTBITE —This condition is considered here because the pathology is similar to that of burns, there being no damage to the vessels, escape of intravascular fluid due to increased permeability and local ischemia from stasis of blood In mild cases (temperature down to 32 F), restoration of tissue temperatures is followed by hyperemia, and extravasation of red cells reaches a maximum about 20 hours after return to normal temperature In severe cases, in which the tissues are actually frozen, the cells of all tissues are directly damaged, and circulatory arrest is due to actual damage of the vascular tree When the vascular tree is damaged, anticoagulant therapy, although advocated in treatment, is not of much use except in the adjacent, partially damaged tissues

The treatment of frostbite has undergone almost as much of a metamorphosis as the treatment of burns Administration of hot stimulants and alcohol is advised for treatment of shock, as is intravenous adminis-

the incidence of electrical burns, and commonly these burns involve one or both hands The lesion differs from the usual thermal burn in that intensive temperatures are generated within the body by the passage of the current Damage to blood vessels, nerves and tendons is common, and if the burn is severe bone and muscle are also affected Apparent progression of the lesion for many days after the injury makes early determination of the degree of injury quite inaccurate This confusion may

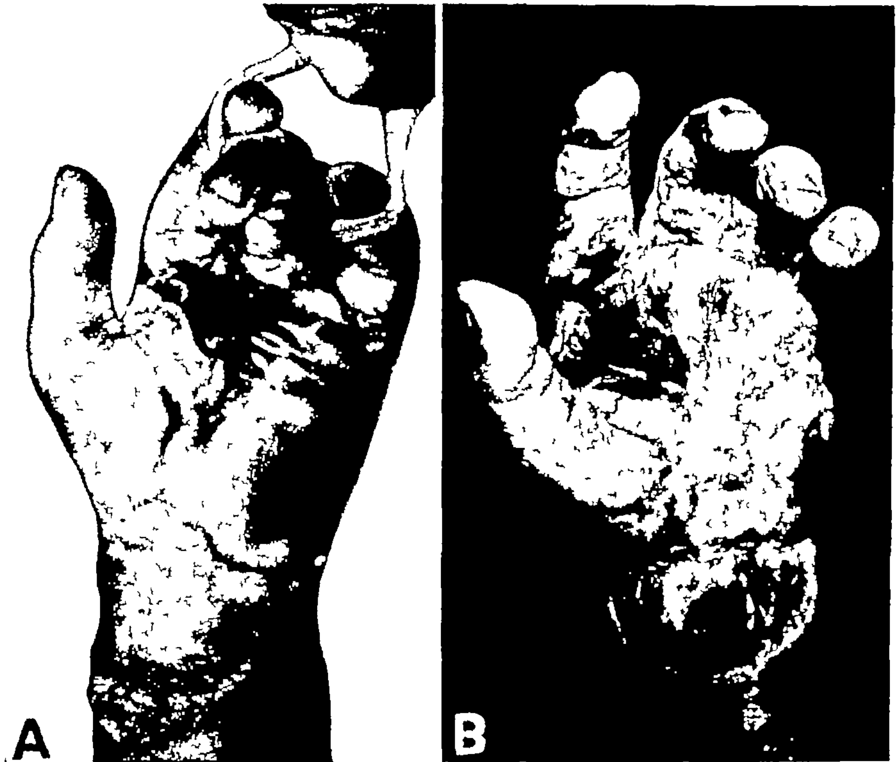


FIG 64 —Electrical burn, with characteristic hidden destruction of deep tissues *A*, first week *B*, third week, eventually all nerves and tendons sloughed The hand was later repaired with flaps

be due to greater damage to deep structures than to skin (Fig 64) The hand of one of my patients, for example, was so cooked that a line of demarcation was almost immediately apparent at the wrist Proximal to this line was good skin and bone, but the arteries were thrombosed to midforearm and the muscles cooked almost to the elbow At the elbow and axilla were small blowout craters presumably due to steam generated inside The anterior surface of one lower leg (his ground) presented a 6 in oval defect about an inch deep, from this the anterior one-half of the tibia soon sequestrated

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tration of fluids when necessary The most recent experiments indicate that rapid warming of the affected area to room temperature results in less vascular damage and is therefore less damaging than gradual warming The warming of the frozen part can be carried out by using water heated to 42 C. This causes considerable pain which should be combated by sedation Rapid warming apparently reduces the anoxia and ischemia in the tissues, increases vasodilatation and prevents stasis of blood Experimentally, less gangrene has developed with this method

CHAPTER SIX

Skin Grafting

CLOSURE OF wounds of the upper extremity when skin is missing may present a complicated problem Skin grafting in one form or another may be required here and may be the only treatment method which results in early return to useful function This form of treatment is necessary in all those injuries in which skin is damaged or destroyed, including burns, avulsions, amputations and various machine tool accidents in which the skin is sliced, chewed, sawed or ground away (sawmill, butcher shop accidents, etc) Burns exceed the other injuries in frequency and severity

Types of Grafts

Methods of filling cutaneous defects include (1) free skin grafting, (2) use of pedunculated flaps from other areas of the body, (3) stretching or sliding of the skin, and (4) local rotation flap procedures

The selection of the type of graft to be used will depend on the wound encountered and the individual surgeon's experience with the different methods In general, the simplest method which will give an acceptable result should be used Poorly planned, complicated procedures invite disaster When subcutaneous adipose tissue or even areolar fascia is still present, simple grafts of split thickness skin will be adequate Complicated wounds in which tendons, nerves, bones or joints are exposed may require transfer of skin and subcutaneous tissue by the pedicle method Even these wounds are often better closed by use of simple, split thickness grafts The more difficult technical procedure of pedicle grafting can then be carried out later as an elective operation The methods involving

sliding of the skin and rotation flaps are rarely applicable in wounds of the hand or forearm Especially in the hand, the defect is usually larger than it appears relative to the available local skin which can be rotated into it, and the skin here responds poorly to pulling, sliding or stretching Z-plasty constitutes a special type of rotation graft which may be useful to obviate scars but is rarely useful in primary repair

FREE SKIN GRAFTS—Great advances in this technic have been made since the introduction of various mechanical devices, such as the Padgett dermatome, to cut skin grafts of proper thickness Grafts may be cut any thickness desired by varying the adjustment on the machine Split thickness or partial thickness grafts have the greatest field of usefulness

Thin grafts (Ollier-Thiersch), from 0 008 to 0 012 in thick, applied to granulating wounds take successfully in a high percentage of cases They will also take on fresh wounds, being used to cover bone, periosteum, muscle, fascia or tendons, and are useful to cover the donor sites of pedicle grafts When large granulating areas are to be covered and donor areas are restricted, a thin split graft may be cut into pieces about 1 cm square and spaced about 1 cm apart on the granulating area. During healing each piece grows peripherally and soon the whole area is covered Although this method uses only about one-third as much donor skin as a graft for the entire area, it leaves an unsightly scar which tends to contract, especially if used around a joint

Thick split grafts (0 018 to 0 025 in thick) should not be used on granulating surfaces or fresh traumatic wounds but they are excellent on clean operative wounds Free thick split grafts have almost superseded free full thickness grafts in definitive hand repair The results are almost as good and the procedure is technically simpler to execute, furthermore, the donor site heals spontaneously

Full thickness grafts should be used only for reconstructive procedures and the thinnest skin on the body should be used as the source

Pinch grafts (Reverdin or Davis grafts) are now seldom used, although once they were the most popular form of graft The technic is so simple that even the occasional operator can perform it with success Its disadvantages are that the percentage of take is not as good as with thin split grafts and that the end result is unsightly The donor site is invariably somewhat scarred Use of this method is discouraged unless nothing better is available

PEDICLE FLAPS—Pedicle flaps are used when later surgery on tendons, bone or nerves will be necessary and must be used when tendons are uncovered in the original wound if these tendons are to slide freely

again Their use is inconvenient to both patient and surgeon, and on the hand they are often bulky and clumsy In case of failure, the hand suffers from infection and the donor site is lost as a source The only type of pedicle which is satisfactory for fresh traumatic wounds is the open, direct flap This type may be converted into a closed system by skin grafting the donor area and any exposed surface of the pedicle The technic of forming a pedicle graft is described in Chapter 7

Donor Areas

When the hand alone requires grafting, not much of a problem arises with regard to donor areas The order of preference in selection of donor sites is anterior thigh, abdomen, chest, lateral calf, posterior thigh, posterior arm Avoid flexion creases Usually the thighs supply the skin for split thickness grafts For pedicle grafting the opposite side of the abdomen or the thigh on the same side is used Sites that may be needed for later pedicle grafting are best not disturbed by previous use as split graft donation sites

Isografts (grafts taken from other individuals) have not yet been successful except in identical twins Occasionally these grafts survive for a number of months but usually they melt away in a few weeks Serious burns that require more skin than the patient can supply can be covered temporarily with fresh cadaver skin Postmortem grafts can be used because skin remains viable for some time after systemic death (see page 111)

Technics of Taking Grafts

No matter what type of graft is used, the operation of skin grafting consists of two steps (1) removing the skin from the donor area, and (2) applying the skin to the prepared recipient area with appropriate dressings The average surgeon doing emergency procedures for hand injuries will get much better results if he perfects his technic in one simple form of skin grafting and adheres to this technic, leaving the more complicated methods to those experienced in reconstructive surgery Split thickness skin grafts are remarkably versatile and their use is recommended They may be removed either by the freehand technic, using the razor, or by some form of dermatome

Freehand grafts —A graft which is cut freehand may be just as good as a dermatome graft, and for small bits of skin the dermatome is probably unnecessary The advantages of the freehand technic are that

special apparatus is not required and the failures which sometimes occur with a dermatome are not encountered However, to remove large pieces of skin by this technic, considerable skill is required

The donor area commonly used is the thigh, although the abdomen or back may be satisfactory The selected area is prepared by shaving, cleansing and applying a nonirritating tinted antiseptic General anesthesia may be used, or the donor area may be anesthetized by infiltration with 1 per cent procaine For infiltration anesthesia, the needle should be introduced beneath the epidermis rather than into it, otherwise the thickness of the graft will be too irregular

The graft is shaved off the donor area using a straight edge razor, a razor blade held in a hemostat or, if available, an amputation knife or a Blair-Brown skin knife A straightedge of wood or the handle of a scalpel blade is pressed down on the skin ahead of the knife or razor blade and the outer epidermis is shaved off, making short back-and-forth oscillations with the knife To obtain large grafts, two flat straightedges must be used, one held stationary behind the knife and the other withdrawn progressively just ahead of the advancing knife edge (Fig 65) The most important technical point is the proper stretching and flattening of the skin just ahead of the knife *

The graft is apt to be cut too thick with this method, and on granulating areas a thick graft will often fail to "take" If the graft is too thick, the donor area heals poorly and with scarring When cut too thin, the freehand graft is apt to become shredded and difficult to handle

Postoperative care of all split thickness grafts is approximately the same and is described in the following sections

DERMATOME GRAFTS —Most of the defects of both the pinch graft method and the split thickness graft cut freehand are eliminated by use of the dermatome The hand-operated instrument consists of a metal half-drum, the surface of which is 10 × 20 cm The drum is supplied with an axle, and radius rods attached to the axle support a sliding knife which revolves over the surface of the drum This knife can be adjusted by micrometer screws or shims to cut at any given distance from the curved surface of the drum †

Rubber cement is used to make the skin adhere to the drum The cement has a tendency to dry and become too thick if left exposed to the air for even a short period and should therefore be poured out fresh just

* The Blair-Brown knife may be fitted with the Mark attachment, a narrow roller bar which flattens the skin and helps to make the graft thickness more uniform

† Instructions given here are for the original Padgett dermatome

before using It should not be stirred vigorously as this creates bubbles The drum of the dermatome should be thoroughly clean and should not be hot

The technic of using the dermatome is more easily mastered than that of cutting split thickness grafts freehand Certain mechanical adjustments

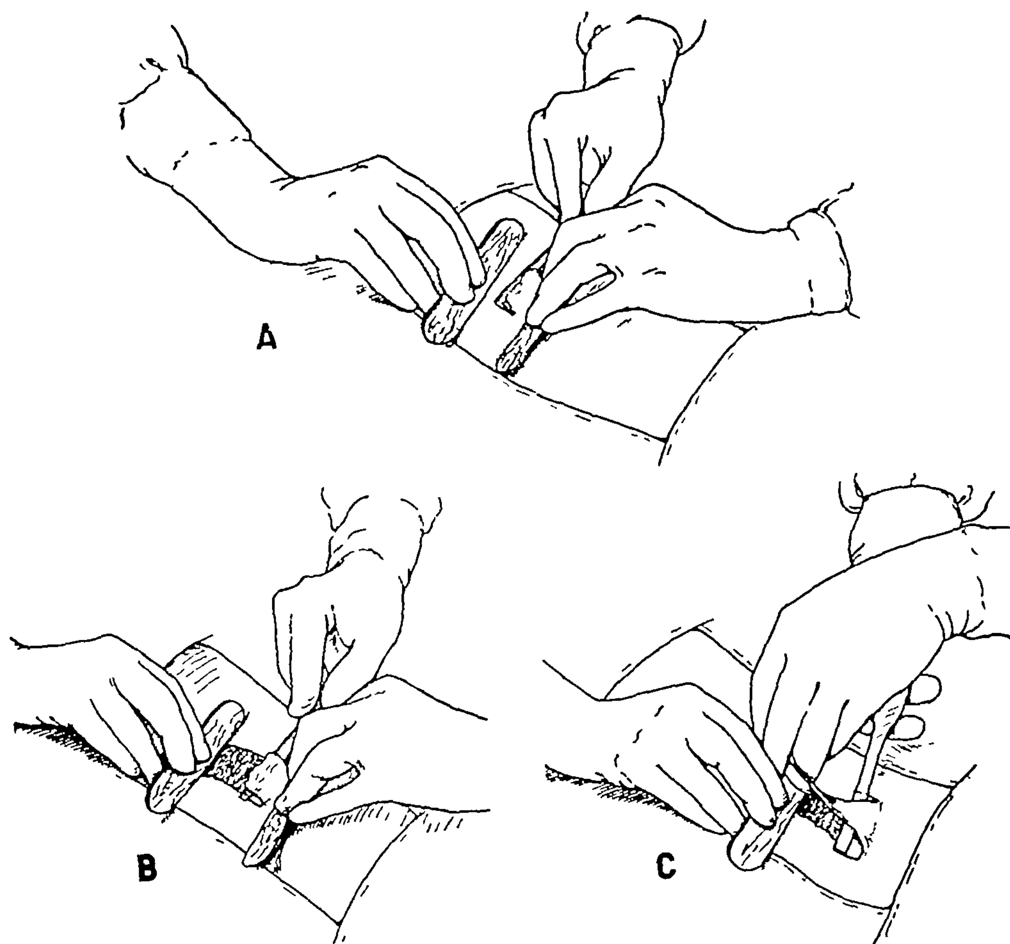


FIG 65 —Freehand technic of cutting skin graft with straight edge razor *A*, surgeon and assistant flatten donor area with tongue blades held just in front of and behind razor *B*, surgeon advances tongue blade ahead of razor as graft is removed *C*, finishing graft

must be made which can only be learned by experimenting with the individual instrument The blade should be new or recently resharpened to obtain maximal success, and an extra blade should be available in case the first one is contaminated These blades should not be boiled but should be carefully cleansed with ether and soaked in some type of cold sterilizing solution The calibration varies a good bit from one dermatome to another, so that it is really preferable to work with only one dermatome and to learn by experience how thick a graft it will cut on a given

setting In the adult the best thickness for a split graft on a granulating surface is about 0 012 in In infants and children thinner grafts are necessary If the graft is too thick, it will not take well over granulations, if too thin, it will be difficult to handle Taking too thick a graft results in delayed healing of the donor area

Any part of the body may be used as a donor area because the skin is pulled up during the cutting process At times it may be necessary to re move skin from irregular surfaces, such as the area over the ribs in a thin patient Depressed areas which would not otherwise be suitable as donor sites can be smoothed out by injecting saline subcutaneously The donor



FIG 66—Dermatome technic *A*, cutting skin graft from thigh *B*, removing graft from dermatome Mosquito hemostats are used to pick up corners of graft.

area should not be prepared with soap and water since water interferes with the action of the adhesive A good method is to dry-shave the donor surface and then scrub it with sterile gauze, using successively ether, alcohol and ether again Local anesthesia may be used provided the point of the needle is inserted at a distance from the donor area, otherwise, procaine or blood may leak from the puncture wound and interfere with the glue A 4 in needle may be used and most of the injection accomplished through one or two skin pricks

The rubber cement or glue is brushed on the dermatome drum and on the donor area as evenly as possible and then allowed to dry for several minutes The dermatome is then pressed against the skin and held there for another minute or so, after which the skin can be pulled up considerably without the drum being detached The operator then leans over so that he can see the knife as it cuts the skin and slowly rolls the drum

along with his left hand, raising the skin up At the same time he cuts the skin with short, even strokes with the right hand, cutting toward himself (Fig 66, *A*) As cutting progresses, it may be apparent that the graft is too thick or too thin or is thicker on one side than the other. This should be corrected by proper adjustment of the instrument while it is still attached to the skin At the end of the drum, the instrument is pulled away from the skin and the graft severed by a final stroke of the knife. Whenever less than a full drum of skin is needed it is usually easiest to use the central area on the dermatome drum The surgeon can

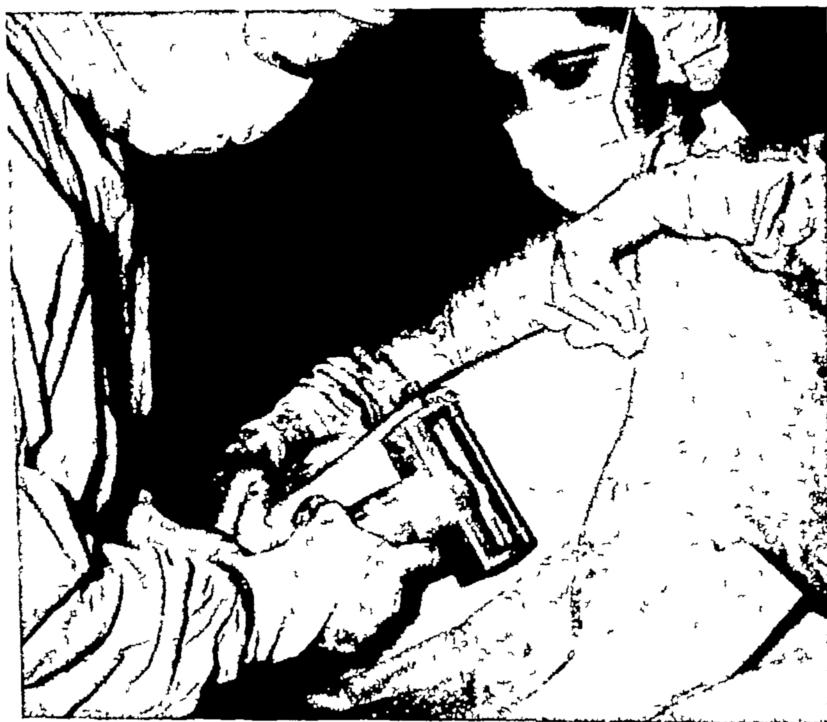


FIG 67 —Electric dermatome.

make a pattern of the defect with a piece of gauze and measure with his eye when he has removed about enough skin with the dermatome, allowing a little extra for fitting

Considerable difficulty is sometimes encountered in removing the graft from the dermatome drum without having it roll up and glue itself together like a carelessly handled piece of adhesive tape To prevent this, the dermatome should be placed on its rack, drum up, and one end of the graft picked up with two mosquito forceps (Fig 66, *B*) The graft is then peeled away slowly from the drum and the sticky surface rubbed with a cotton ball containing glove powder, sulfanilamide crystals or

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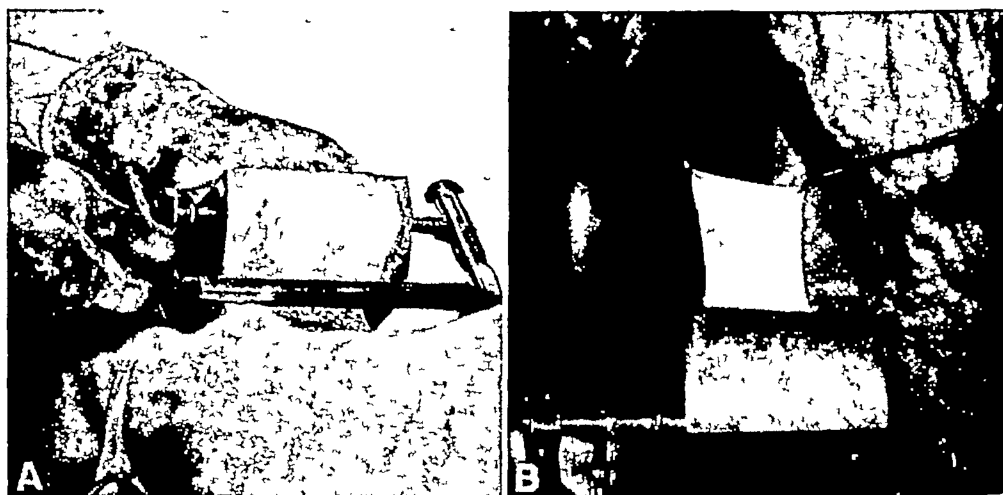


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OTHER TYPES OF GRAFTS—*Pinch grafts* are rarely needed with the various instruments now available This once popular method has now been superseded by the postage stamp graft Pinch grafting disfigures the donor area and gives a cobblestone appearance to the grafted area Figure 68 illustrates the simple technic With the scalpel and needle a

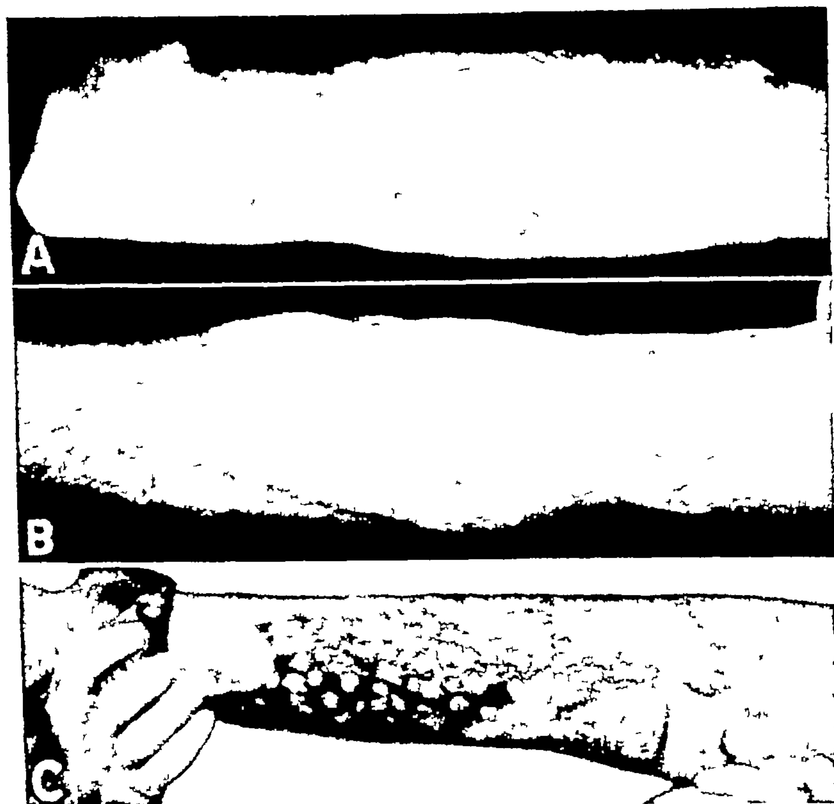


FIG 69—*A*, patch grafting of third degree burn of arm Multiple body burns (from explosion of galvanizing machine) made patch grafting desirable to economize on skin With one drum of skin removed from thigh and cut to postage-stamp size, an area 6 × 12 in on arm was covered Later, because contracture of the antecubital area developed and the patient objected to appearance of grafts, the entire scar was excised, local flaps were shifted to the antecubital area and the rest was grafted with full-sized split skin grafts *B*, area after revision *C*, severely burned extremity covered with a variety of grafts including split thickness, pinch and patch grafts

small disk of skin is cut from the donor area This disk may be anywhere from 1 mm to 1 cm in diameter but should not be thicker than the actual epidermis No fat should be present on its under surface The little patches of skin are transferred directly to the recipient area as fast as they are cut and are simply placed loose on this area or perhaps pressed down into the granulations a little Any bleeding point on the granulating area is avoided because it will float the graft away The object of

fresh blood When the other end of the graft is reached, two more mosquito forceps are applied and the square of skin is lifted over to the recipient area. It is best not to soak the graft in saline, as this removes the plasma from its raw surface Drying of the graft should be avoided Surgery lights which are too hot should be turned away, and the upper surface of the graft may be sponged from time to time with saline

Electric dermatome—This instrument (Fig 67) is easier to use than the drum machine, but the skin obtained with it is not quite as uniform Its principal advantage is in the treatment of burns requiring large quantities of skin applied in a minimum of time. The technic of using it is much like the freehand method The skin of the donor site is first

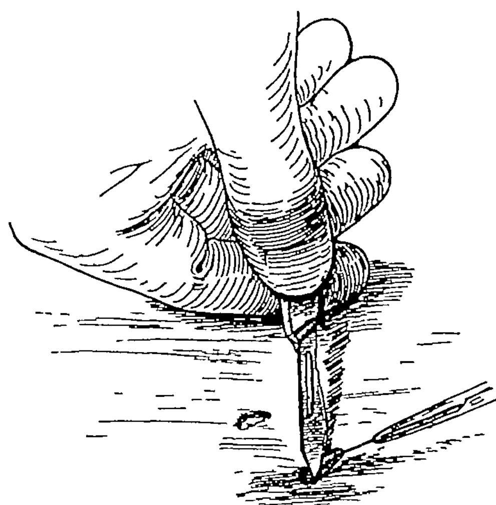


FIG 68—Technic of removing pinch graft. Needle is jabbed into skin and upward traction made to tent up an area about 0 5 cm in diameter This is cut off with the scalpel. This method is now rarely used

lubricated with mineral oil and is flattened and stretched ahead of the instrument The dermatome is pressed against the skin of the donor site and then turned on It should be advanced at the rate of about an inch every one or two seconds, firm even pressure being meanwhile maintained between the dermatome and the skin As with all dermatomes, the knife should be new and the instrument in good working order, and the operator should practice with it for optimum results Varying the pressure against the donor site will vary the thickness of the graft so some tactus-eruditus is essential A calibrated thickness adjustment lever is present on the end of the machine which must be experimented with before the correct thickness of graft can be obtained The width of the graft is varied by using different sized gates on the machine

When this is done a dry fine mesh gauze is applied immediately to the donor area and covered by a thick, hot, moist sponge to aid hemostasis At the end of the operation, the sponge is removed and the blood-soaked fine mesh remains as the only cover A firm coagulum forms, this hardens in 24 hours and remains until the skin heals in about 2 weeks

Preparation of Recipient Area and Placing of Graft

The proper preparation of the recipient area is actually just as important in obtaining success in skin grafting as the technic of taking the graft Recipient areas may be classified into three types (1) fresh clean wounds created surgically, as in the excision of scars or growths, (2) fresh contaminated traumatic wounds, and (3) granulating areas left by burns or partly healed wounds

Fresh clean surgical wounds—These are usually not in the domain of traumatic surgery There are, however, occasions when a local flap may be shifted to cover a potentially contaminated wound The donor area left could be considered a clean surgical wound Similarly, the formation of an abdominal flap creates a clean surgical wound which calls for grafting Covering such an area with split thickness skin is one of the easiest and most successful of all grafting operations This area usually has a base composed of fat, areolar tissue or fascia Commonly there are no irregularities or cavities in which it is difficult to obtain firm, even pressure

In grafting of these wounds minute attention to hemostasis is essential Every bleeding point should be controlled with forcipressure or, if necessary, by tying with a minimal amount of 5–0 plain catgut or 5–0 silk Just before the graft is placed, every bit of blood should be sponged away from the wound and a final inspection made for bleeding points The graft should be laid in place under approximately normal tension, if too loose it will wrinkle and if too tight it will pull away from the edges It is tacked down at three or four strategic points, and a running mattress suture of fine silk is then used all the way around the edge This everts the edge of the graft against the edge of the wound and results in better healing than a simple over-and-over stitch Any redundant parts of the skin graft are trimmed away with scissors as the stitching proceeds Sometimes, when the area is very large, it may be partially closed by suturing the subcutaneous fat to the underlying fascia along the two sides where most relaxation is present The graft and the underlying wound

the procedure is not to cover the granulating area completely but to apply enough epithelial islands so that rapid covering will take place Fifty per cent of the total area should be covered, the grafts evenly distributed over the whole area Sometimes pinch grafts result in partial take over an infected area which encourages the occasional operator to use them

The *patch graft,* also called the postage stamp graft, is made by cutting up a piece of split skin It is much better than the pinch graft and accomplishes everything that the pinch graft does In this method the dermatome is used to remove a drum or two of skin cut almost 0 012 in thick. Each sheet of skin is cut with scissors into small 1 in squares These are transferred to the recipient area, spacing them about ½ in apart (Fig 69) To facilitate handling, the skin may be backed with gauze before it is cut up To accomplish this the skin is spread out on a sterile pan, raw side down, the outer surface is coated with dermatome glue, and glue-coated gauze is applied to it The backing peels away a week later when redressing is done

Dressings for either pinch or patch grafts should consist of a single layer of grease gauze or mesh next to the wound, covered with dry gauze and compressible material and all fastened down with Elastoplast so that the dressing will not slide around Do not redress for at least four or five days

The grafts may be protected by a single layer of coarse mesh gauze, which is attached to the surrounding sound skin by dermatome glue Dressings may be changed down to this gauze every day and if necessary saline moistening applied

Free full thickness grafts are rarely necessary These are cut with a scalpel The usual method is to make a pattern of the recipient area, transfer the pattern to the donor area and outline its exact size on the skin with ink An incision is made around this area and the skin lifted up with hooks or sutures and cut away, care being used to take no fat with the skin The donor area must be closed by split thickness grafting or by suturing the edges together

Dressing Donor Areas

Most donor areas are dressed by a single layer of fine mesh grease gauze followed by absorptive compression dressings In some situations, as in very hot climates or when most of the body is already covered, it may be advantageous to use the exposure treatment on donor areas

wound Theoretically, in preparation of the area everything should be considered contaminated and an attempt made to convert the contaminated wound into a clean one by an economical excision of the area In actual practice, such a procedure is rarely possible The operator, therefore, should prepare the surrounding skin and the wound itself as in any fresh injury of the hand (see Chapter 2). In injuries in which the six hour time limit has been exceeded a decision will have to be reached—whether to use primary skin grafting or to allow the area to granulate and perform secondary wound closure later I prefer primary grafting for practically all wounds which need it, because a successful take is a great advantage to the patient and an occasional failure is no great loss (Fig 70)

The irregularities in depth and in the type of tissue make skin grafting much more complicated on a traumatic wound than on a surgically created area Every bit of foreign material and devitalized tissue must be removed If tendons or bones are exposed, they may sometimes be successfully covered if it is possible to draw a layer of live areolar tissue or fat over them with a suture or two before the skin graft is applied Hemostasis must be absolutely complete Any declivities to which the skin graft cannot be easily applied should preferably be eliminated by suture or by saucerizing the surrounding area The outline of the defect does not have to be regularized, but any tattered loose skin tags which are devitalized should be excised (see Chapter 7) During the thorough revision of a complicated wound to prepare it for skin grafting it may become apparent that a pedicle flap will be needed Usually this contingency can be anticipated

After the traumatic wound is completely prepared, the skin graft should be loosely fitted into place and tacked around the edges with interrupted sutures, usually silk, which are left long Grease gauze is applied over the skin graft and a thin layer of gauze which extends out beyond the skin graft added This dressing is covered with a layer of cotton balls or other compressible material carefully piled on so that any declivities under the graft are filled and soft, even compression is maintained over the grafted area The long ends of the sutures are gathered together and tied over the top of the cotton balls and gauze (Fig 71). To prevent the graft from slipping, additional pressure is applied by further layers of gauze, an Ace bandage and Elastoplast strips Almost all traumatic wounds require immobilization after grafting since any movement of the underlying muscles, tendons or joints will result in disturbance of the graft and failure to obtain a take Any form of splinting which may be

should not be allowed to dry out excessively Any bleeding caused by the sutures can be controlled with pressure and any clots which form under the graft removed with applicators soaked in saline

A little pressure over any skin graft is important during healing To compress this type of graft, several layers of compressible gauze sponges are cut approximately to match the grafted defect. A single layer of petrolatum gauze is placed over the graft itself, then the thick gauze compress which has been cut to fit is applied and sewed in place, using a running stitch of no 36 wire which passes back and forth across the gauze dressing until a wire lattice has been formed over the graft A little more dry gauze over this and some Elastoplast complete the dressing



FIG 70 —*A*, hand caught in sand-slinging machine, with destruction of soft tissues of palm and volar surface of fingers *B*, after primary repair ring and little fingers were skin-grafted and long finger filleted and used to cover palm, index finger and thumb amputations completed, using existing flaps Further repair using pedicle flaps was done later (see Fig 204, *C*)

Unless complications develop, there is no need to inspect this wound before seven days, at which time the sutures may be removed and the graft should be healed If dermatome glue has been left on the graft, it will tend to stick even to petrolatum gauze, and the original dressing should therefore be removed carefully Any small unhealed areas found at this time epithelize rapidly under grease gauze dressings

FRESH CONTAMINATED TRAUMATIC WOUNDS—As has been mentioned, there are many situations in which skin grafts should be used on fresh traumatic wounds of the upper extremities The selection of a skin graft for such a case is the same as for a fresh surgical wound—thin split thickness grafts give the most successful takes Preparation of the area to be grafted is more complicated than it is for a freshly created surgical

dressings can be removed at the end of seven to 10 days and simple grease dressings applied until the graft matures

GRANULATING AREAS LEFT BY BURNS OR PARTLY HEALED WOUNDS —The preparation of a burned area for grafting has, as discussed in Chapter 5, a great many different aspects Not only must the wound be prepared, but the patient's general condition must be improved to bring the wound into the best possible state The local slough is removed, using daily dressings if it is thin or enzymes or surgical excision if it is thick Although good results are reported with use of primary excision or of late excision followed by immediate grafting, the balance of opinion continues to favor the grafting of a healthy granulating surface as the preferred method of closing burn wounds * To produce healthy granulations a variety of agents are employed, including some which are also used to remove burn sloughs As the wound heals it casts off dead tissue as a slough, at the same time forming granulations on viable tissue Retained foreign bodies, nonviable tissues and pockets in which wound secretion can collect produce exuberant granulations which perpetuate infection; these conditions are inamicable to successful grafting Even the simplest procedure, such as repeated dressings, wet or dry, with or without application of various chemicals, will tend to prevent unhealthy granulations if foreign bodies and dead tissue are removed The application of pressure aids in keeping the granulations firm and smooth Success with one type or another of chemical dressing will frequently convince the student or practitioner that a certain agent is efficacious The wide variety of pharmaceutical preparations (or complete absence of them) used in different cities suggests that the drug used is not important

The final debridement and preparation for grafting of a burned area (page 111) should be done during the third week. Under general anesthesia all devitalized tissue is removed, exuberant granulations are scraped away and everything is done to clean the wound as thoroughly as possible Gauze dressings are then applied to the raw areas and the patient returned to the ward Transfusions may be necessary either during or after the operation because of excessive bleeding from the raw area Three to five days should be allowed to get the granulations in the best possible condition for grafting As outlined previously, either wet or dry dressings may be used during this period As soon as the granulations appear to be in the healthiest possible condition—firm, red and shiny—skin grafting should be carried out One of the indications that the skin

* See Immediate Grafting, page 108

improvised to accomplish the purpose is satisfactory Usually plaster of paris splints molded around the extremity are most comfortable and efficient

Postoperatively, grafts which have been applied to traumatic wounds

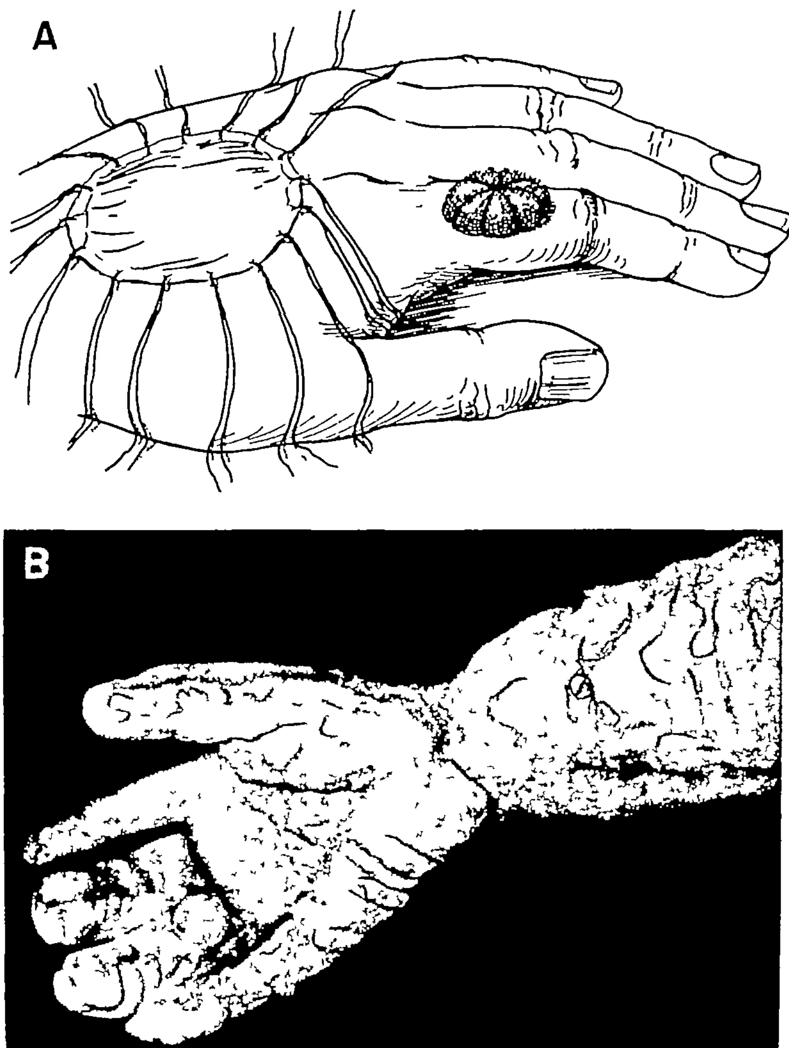


FIG 71 —Stent type of dressing for skin graft. *A,* sutures holding graft are left long, layer of petrolatum gauze is placed over graft followed by dry gauze and cotton balls, and sutures are then tied over all. *B,* dressing tied on three fingers, thumb and forearm

require closer supervision than those applied to clean wounds After four or five days it is usually advisable to remove some of the dressings to ascertain the condition of the graft If any moisture is present, all dressings and sutures should be removed and moist dressings applied to the graft, with daily changes If there are no complications, the sutures and

remain, according to the individual operator's preference, but the skin produced by these regenerating areas is usually not as good as the skin supplied by the graft The same is true of areas which have recently skinned over with thin, shiny epithelium After the granulations are removed, hemostasis is obtained by applying dry gauze with pressure The graft is then taken with a dermatome, fastened into place and dressed in the manner described for fresh traumatic wounds

The elasticity of the graft allows a certain amount of leeway for fitting irregularities along the edge, but some trimming to make the graft fit may be necessary. The extra pieces are often useful to apply to small areas which may be separate from the main burn surface If any bleeding is present or clots form under the graft, the clots should be sponged away with cotton on applicators inserted between the sutures and further pressure applied until bleeding stops It may be necessary to elevate the limb, apply a tourniquet, remove the clots and apply a pressure dressing with the tourniquet on

Staged procedures.—When, for example, one entire upper extremity has suffered full thickness burns, it may require as many as ten drums of skin taken with a dermatome to cover it adequately This is a formidable procedure and usually cannot be accomplished in one operation Grafting is therefore done in stages when the raw area is too large to cover in one session or when the wound has not cleaned up evenly and some areas are not ready The patient is kept in the best possible physiologic equilibrium by use of frequent transfusions and other measures, and at intervals of five to seven days grafts are applied to the most healthy appearing areas The whole wound is dressed with gauze soaked in saline, and tubes are inserted in the dressings to keep moisture constant

Postoperative care—The importance of constant pressure† and immobilization cannot be overemphasized Postoperatively, the prophylactic use of antibiotics and elevation of the part aid in securing primary healing If a portion of the graft separates while the graft on the rest of the wound is satisfactory, the primary dressing is removed and moist dressings applied

Split thickness skin grafts on burns, when first healed, appear rather fragile and sometimes blister, but in general the quality of the skin so supplied is better than that which develops with spontaneous regeneration Repeated applications of lanolin aid in toughening up the grafts Movement of the joints should be encouraged as soon as the grafts are

† Experimental evidence indicates that it is possible to have dressings too tight as well as too loose

grafts will take is the appearance of a ring of epithelium growing in from the edge of the wound (Fig 72).

Exuberant granulations should be removed before the graft is applied These granulations may be scraped off with the handle of a scalpel or

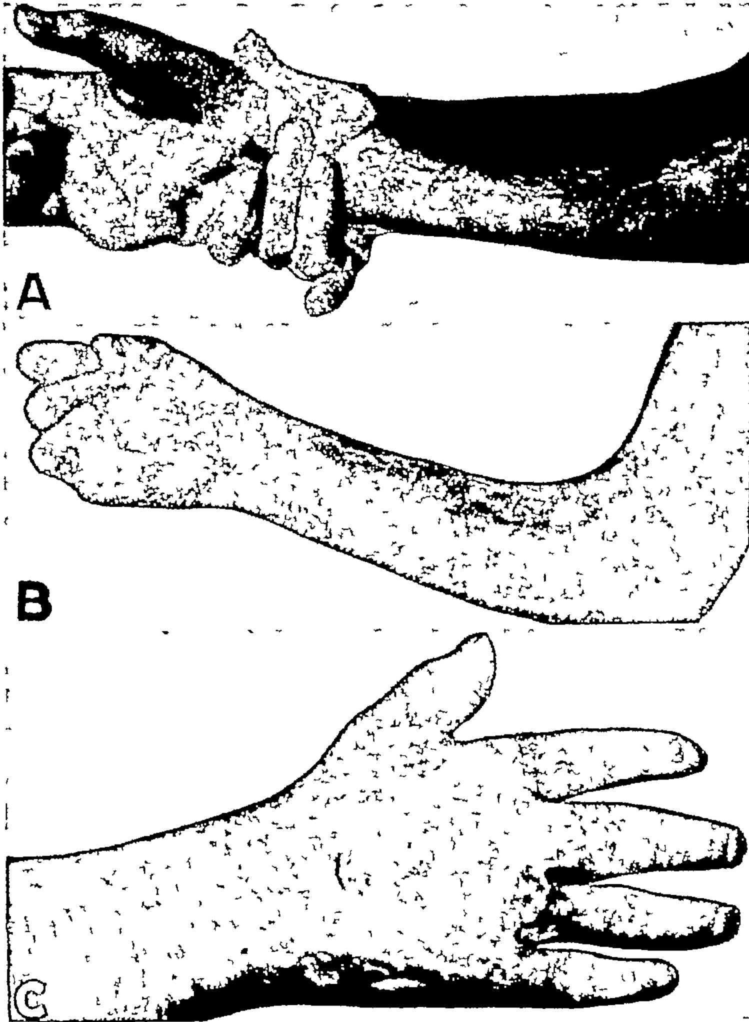


FIG 72 —*A*, granulating surface ready for skin grafting firm, shiny granulations and ingrowth of epithelium from edges *B*, after grafts healed *C*, post-traumatic edema of hand with multiple granulating wounds treated by skin grafting with eventual restoration of function See also Chapter 3, page 63

trimmed back with a pair of sharp scissors curved on the flat The ring of epithelium growing in from the periphery of these wounds which is very loosely attached to the granulating surface is best removed There may also be scattered islands of regenerating epithelium appearing as grayish spots on the granulating surface These may be removed or allowed to

CHAPTER SEVEN

Avulsions of Skin: Primary Flap Grafts

AVULSION OF the skin from the extremities is a fairly common injury Every surgeon sees a few cases, attempts to replace the loose skin and finds that it soon becomes gangrenous In 1939, Alfred Farmer of Toronto reported a new method of treatment in which the avulsed skin was excised, the subcutaneous fat removed and the skin sutured back into place as a free graft This method has also been advocated by Sir Harold Gillies, Halfdan Schjelderup and Carleton Mathewson, all of whom report excellent results

ETIOLOGY AND PATHOLOGY

The skin may be avulsed from the body by a variety of forces which either crush, pinch or tear, with the result that the skin may be burst loose from its attachment, torn away in shreds or peeled down like a stocking or glove In any event, a tangential force is applied which starts the skin sliding and tears the attachment between the subcutaneous and deep fascia At times this tearing may separate the skin from the underlying tissues and cause gangrene of the skin without any open wound being present

Whatever the original force and whatever the direction in which the flaps are torn loose, gangrene probably develops from a circulatory derangement Unquestionably, interference with venous return occurs, with passive congestion followed by thrombosis and hemorrhagic infarction

healed After about a year the graft assumes a very normal appearance and there is little scarring If the split thickness skin grafts are not satisfactory, they may later be replaced with skin applied by the pedicle method or by full thickness skin grafts The most important function fulfilled by any skin graft is that of covering the raw area and permitting early return of function to the hand It is important not to wait too long before grafting, otherwise extensive changes take place, the joints are drawn into bizarre positions, and the balance of the hand is destroyed

Replacement of Skin

Incomplete avulsions—An incomplete avulsion of the skin is a more common injury than a complete avulsion Whether this skin can be reapplied successfully or not depends largely on its blood supply. If the attachment is proximal, so that the arterial supply of the skin region is intact, and if the length of the avulsed skin does not exceed approxi-

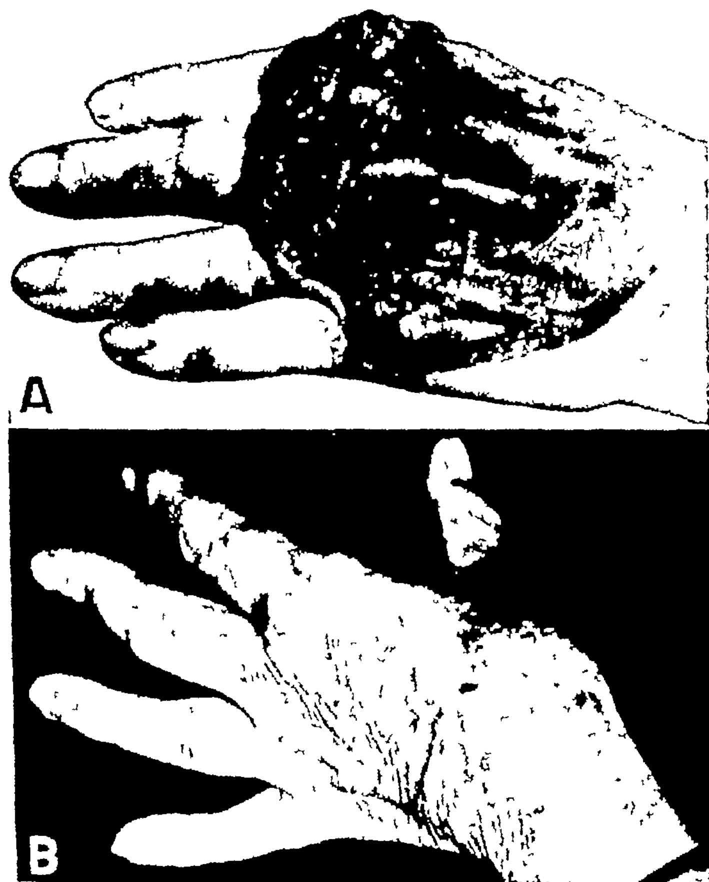


Fig 73—*A*, avulsion of skin of back of hand from auto accident Excision of subcutaneous tissues and replacement of skin as graft resulted in full function *(B)*

mately twice the width, the entire avulsion may be sutured back into place, provided it can be rendered clean and the repair is carried out without injury to the blood supply In many cases the length of the avulsion is more than two and one-half to three times the width In others, the blood supply of the avulsed skin is poor—for example, when the avulsed skin is only attached distally—and prospects of the flap surviving when sutured back into place are poor even if the length-to-breadth pro-

When the tissues are torn off from above downward so that the flap is based distally, it is easy to see how interference with venous return would follow. However, if the skin is simply torn loose from its deep attachment without being lacerated, it is more difficult to understand why gangrene occurs

Once gangrene has developed, the tissues will not heal spontaneously any better than a deep burn will The gangrenous portion first sloughs off, granulations appear and the epithelium grows in from the edges with scarring and contracture

DIAGNOSIS

In any avulsion type of injury the usual diagnostic tests should be carried out even though the type of injury seems obvious The function of the tendons and nerves in the hands should be tested, and an x-ray should be taken because there is often an associated fracture or loss of bone

Avulsions customarily are classified as incomplete or complete, depending on whether some pedicle still exists between the avulsed tissue and its original bed or there is a complete loss of circulatory contact Incomplete avulsions are secondarily classified into those with a proximal and those with a distal pedicle The treatment varies considerably for the different classes The location of the avulsion is also important Where the fat is thick, as in the palm, the volar surface of the finger and about the thenar eminence, the treatment differs from that for areas in which the skin is thin The condition of the avulsed skin is of significance Badly crushed or frayed skin will not recover as well as skin that is cleanly torn away

TREATMENT

Treatment should aim toward restoration of skin continuity as quickly as possible Replacement of the avulsed flap is frequently followed by gangrene or partial gangrene This is particularly true if the subcutaneous fat is thick and heavy, as in the palm of the hand and sole of the foot, or if the skin is pulled away like a glove or stocking with the pedicle based distally. Whether the avulsed flap is excised and replaced with the same skin as a Wolfe graft, by Thiersch grafts taken from elsewhere or by an abdominal flap would seem to depend on the individual case In many instances, in the forearm at least, a part of the flap is viable and the rest of it is dead

portion is less than two to one. In these instances, the recommended procedure is to divide the pedicle, excise the subcutaneous tissue and use the avulsed skin as a free graft (Fig 73) Unquestionably excision of the subcutaneous fat is the most important step in this procedure, particularly when the skin is still intact but is avulsed from its deep attachments, as in wringer injuries In these, a fluid composed of necrotic fat, serum and blood collects between the skin and the tissues beneath Immediate incision and drainage to eliminate these collections is indicated If the subcutaneous fat is seen to be necrotic, it should be removed If the avulsed area is small a single incision may be adequate, if large, multiple incisions, kept open by drains if necessary, and gentle pressure dressings, to keep the skin in apposition to the deep tissues, are indicated

In actual practice it is difficult to lay down hard and fast rules on treatment of incomplete avulsions Many times there are numerous small tabs or flaps of doubtful viability which, when sutured back into place with a few nonconstricting sutures and dressed with pressure, will show a remarkable tendency to recover. As a compromise measure, one may suture all the flaps together loosely, apply pressure dressings and keep the extremity elevated for about four days At the end of this time, it will be fairly obvious if circulatory changes have taken place, and usually only portions of the avulsed skin will have died The patient is then returned to surgery and the areas of gangrene are excised, the wound is rendered relatively sterile by the application of a mild antiseptic, and a split thickness graft is applied to the defects (Fig 74)

Suturing of a partial avulsion back into place may be followed by a venous thrombosis either in the entire thickness of the flap or in the subcutaneous fatty tissues Arterial pressure being high, blood is able to enter the tissues, but venous pressure being low, blood cannot get out through the collapsed, kinked or compressed veins The proper dressing of these wounds requires considerable skill, since just enough pressure must be applied to prevent undue swelling yet not interfere with the circulation, especially on the venous side Venous thrombosis is particularly apt to occur in the palm where subcutaneous fat is heavy In such an area, following replacement, the avulsed skin will become indurated and appear subacutely inflamed A cellulitis-like reaction develops in the surrounding tissues, and the replaced skin may blister and become gangrenous or may continue to be viable After healing, there are pronounced scarring and contracture and the skin is of poor quality This complication can be avoided by excising the subcutaneous fat and reapplying the skin as a free graft

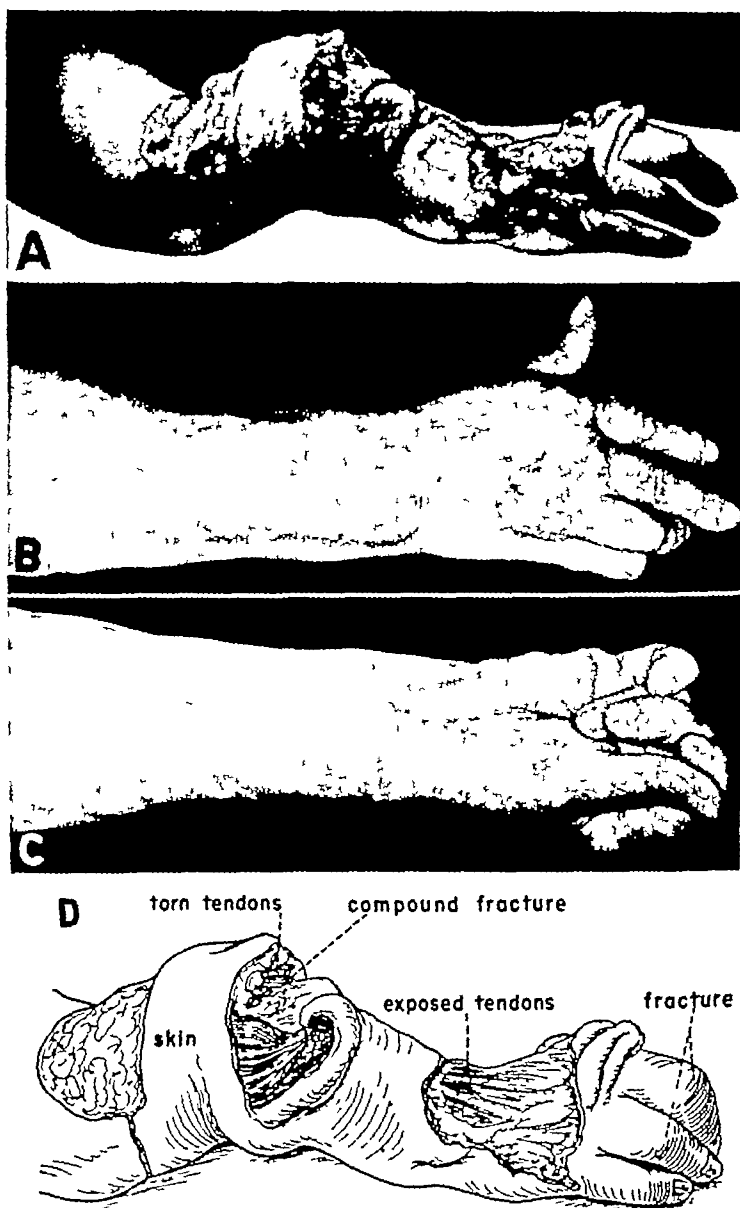


FIG 74—*A*, multiple open fractures of forearm and hand and avulsion of skin in arm caught between car door and telephone pole Repair included immediate fixation of fractures, replacement of skin flaps and splinting *B* and *C*, end result. (From Nichols Am J Surg. 83 364-371, 1952) *D*, diagram of injury Most of the avulsed skin was salvaged, two weeks after injury an area 3 × 4 in was replaced by skin graft

cannot be controlled at the time surgery is carried out, a few drains should be left tucked under the edges of the flap These drains are best removed after 48 hours, at which time any additional serum can be expressed and pressure carefully reapplied to the flap If, at this time, it is obvious that an extensive area in the avulsed skin is not viable, the patient should be returned to surgery and the thrombosed area trimmed away and replaced with a split thickness skin graft Usually 48 hours will not be long enough if the viability of the flap is only doubtful Sometimes the skin itself is quite purplish, due to venous congestion and infiltration of blood, yet will survive and provide good covering

Repair with Pedicle Flap

When tendons, nerves or bone are exposed, the surgeon may, at times, elect to use an abdominal flap to cover the defect (Fig 75). Any transfer of tissues from one region of the body to another by the flap or pedicle method strains the viability of the tissues to the utmost, and there is a large chance of failure even with the simplest possible procedure Notwithstanding this fact, general surgeons can make successful flaps for the hand provided they use the correct technic

Technic—Having made a minute debridement of the hand itself and having determined that a flap is desirable, the surgeon should examine the patient to determine whether or not an abdominal flap is likely to be successful The best subject for this procedure is a fairly young, thin person with moderately loose skin and freely movable joints The forearm is first positioned against the abdomen to see where the flap can be located so that the defect can be easily covered with the arm still in a fairly comfortable position With the defect on the ulnar border or dorsum of the extremity the flap is usually based downward and is either midabdominal or epigastric in origin For a defect on the radial border or volar side of the arm, the flap is based upward and is supplied by the upper abdomen or pectoral region Palmar defects may be covered primarily by using a flap containing the superficial epigastric vessels This flap should always be lined with skin

If a primary flap is used (Fig 76), any skin of doubtful viability about the periphery of the extremity wound should be excised and any irregularities here overcome either by stitching adjacent skin tabs together along the edge or by excising them A simple cloth pattern is made by laying a thin towel or piece of gauze against the defect and cutting around it with a pair of scissors The arm is then placed against the

COMPLETE AVULSIONS—Although the skin may be completely avulsed from the forearm or hand, it is frequently still hanging onto the arm or may be brought in by the patient or by the first-aid man This skin, which usually has subcutaneous tissue attached, can sometimes be replaced even if completely detached. The loose piece or pieces should be thoroughly scrubbed on both sides with soap and water and a scrub brush to render them relatively sterile The wound should be thoroughly cleansed and every bit of nonviable tissue, such as dangling muscles, shreds of fascia and loose bone, excised The detached skin is placed upside down on a sterile, flat surface and the subcutaneous fatty tissue carefully cut away, using a scalpel or scissors curved on the flat Every bit of subcutaneous tissue and even the lowermost level of dermis should be sacrificed The skin is then sutured back into its original position as a free full thickness skin graft

This method is especially applicable when the deep fascia is intact, the damage to the underlying muscles, tendons and nerves is minimal and the skin is not crushed The quality of the replaced skin, if the procedure is successful, may be better than that from a free split thickness graft, and ultimately the appearance of the damaged area may be almost normal

In complete avulsions in which the skin is not available, the defect must be closed either by *a split thickness skin graft* or by a pedicle flap from the abdomen A split thickness graft may have to be used as a primary biologic dressing regardless of the extent of underlying damage It is not always the best repair, because tendons will not slide beneath it and it will not carry any weight when placed over bare bone, etc However, it can make a cover and prevent the loss of tendons which would otherwise slough, and its use permits secondary reconstructive procedures to be carried out more simply

POSTOPERATIVE CARE—Whenever avulsed tissue has been replaced by a free graft or as a local flap, a great deal of additional care is necessary postoperatively Because the underlying tissues are potentially infected and the quality of the skin used as a free graft may be poor, these wounds should be constantly watched for sepsis Elevation, compression and rest of the extremity by proper splinting is important, and a course of antibiotic therapy should be given for the first five to seven days If the surgeon is in any doubt about the condition of the graft, the wound should be inspected earlier than usual—possibly at the end of five days—and if any areas have become gangrenous they should be trimmed away

In replacing the local skin as a flap, and especially if all the oozing

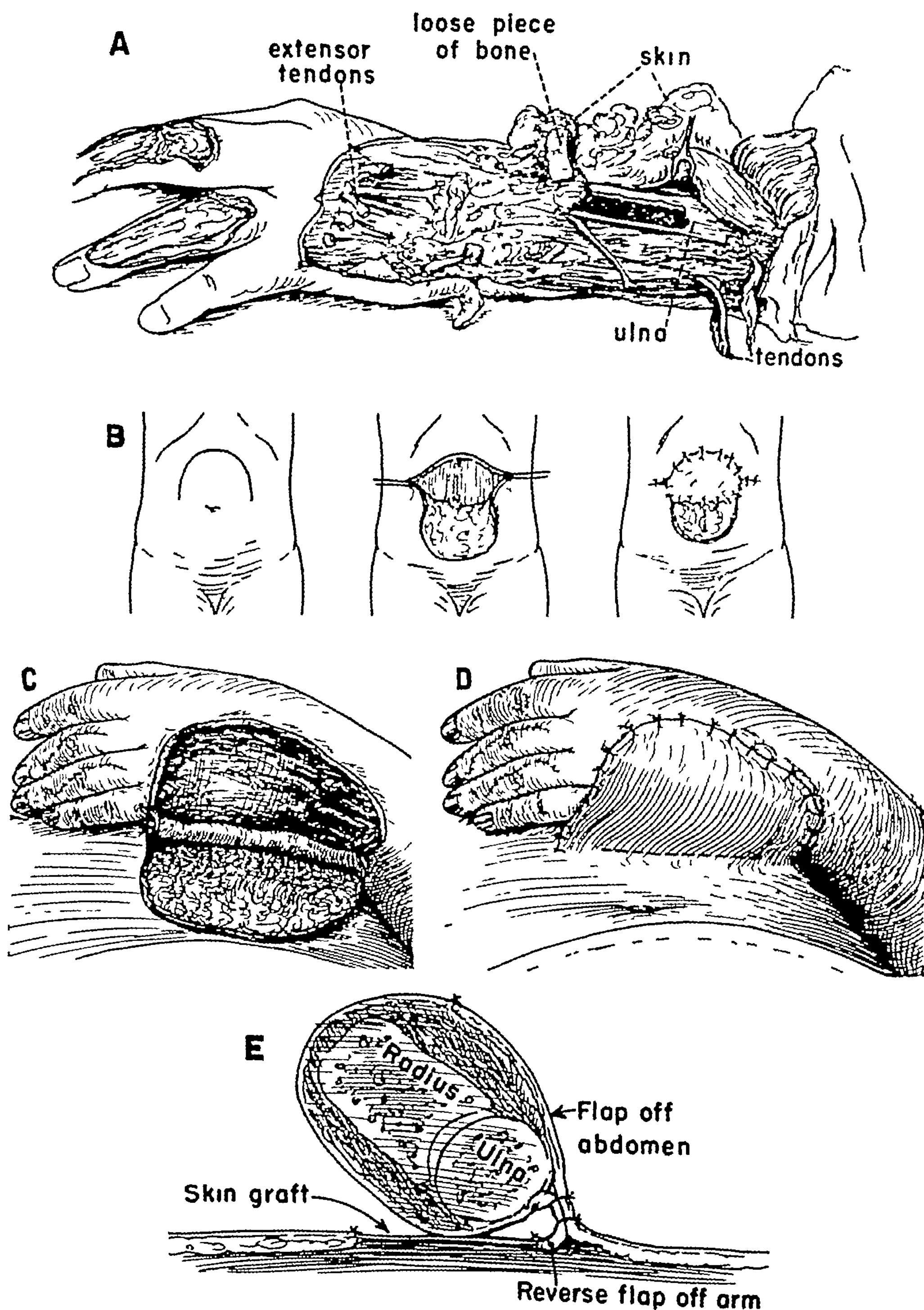


FIG 76 —Abdominal flap technic *A*, original injury (see Fig 75) *B*, formation of abdominal flap, with split thickness graft applied to donor area. *C*, hand wound debrided and skin flap from ulnar border of hand sutured to abdomen *D*, defect closed with abdominal flap Dotted line indicates incision for delay *E*, cross-section showing double-hinge principle and skin graft of donor site

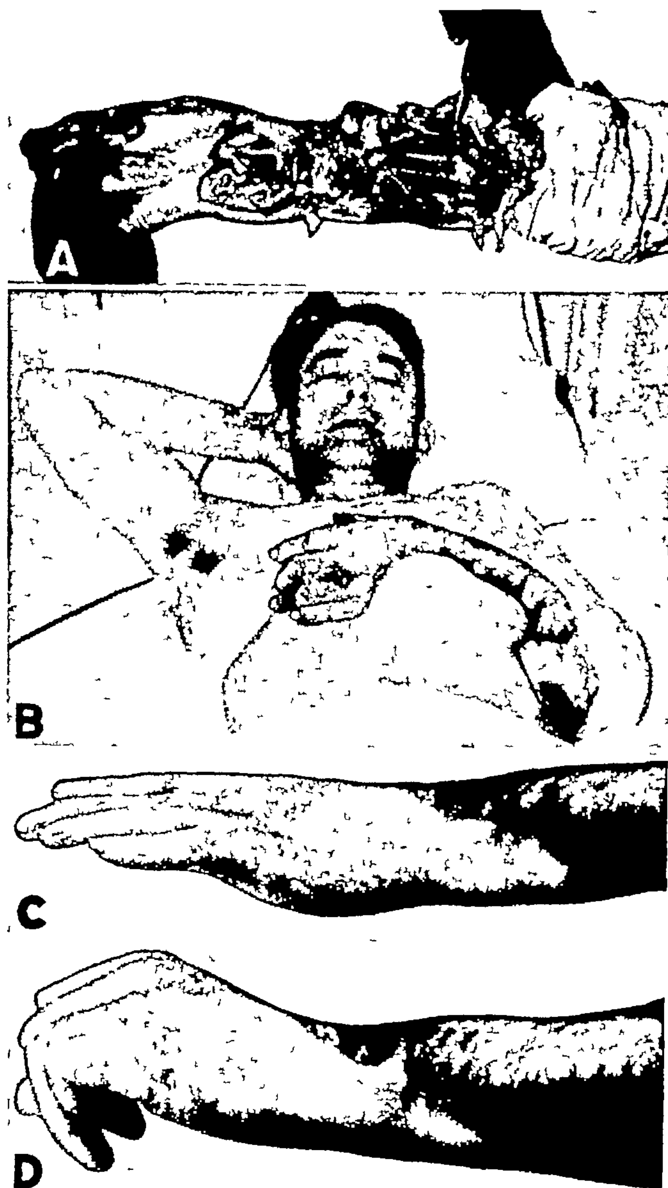


FIG 75—*A*, hand caught in head rig at sawmill with multiple open fractures and loss of extensor tendons, skin and bone *B*, after primary repair of injured structures and application of abdominal flap *C* and *D*, end result, redundancy in flap was excised and pedicled fat sandwiched under tendons (From Nichols Am J Surg 83 364-371, 1952)

is sutured to the edge of the abdominal wound opposite the flap It also may be necessary to drain the undermined skin remaining on the abdomen Serum collections and hematomas in these regions, even when they collect away from the original abdominal wound, may seriously interfere with the circulation in the flap

The arm and forearm should be fastened to the body either by plaster of paris splints or by voluminous adhesive dressings padded over the bony points, a window should be left open so that the flap may easily be inspected The relative position of the flap on the forearm should be ascertained when the patient is returned to bed from the operating room, and the nursing staff instructed to recheck this area while the patient is recovering from anesthesia and every two or three hours during the first day or two By doing this one avoids the tearing out of the sutures or kinking of the blood supply or hematoma formation

A properly applied flap will heal onto the forearm as quickly as the local skin will heal For safety's sake the sutures should probably be left in a few days longer than the usual week It requires about three weeks for a flap to develop its blood supply from the forearm so that it can be severed from the abdomen safely If the entire defect on the arm has been covered at the first stage, it is usually perfectly all right to sever the skin from the abdomen and close the wound between this freshly cut edge of the flap and the forearm skin in one stage

If the flap from the abdomen has not completely covered the forearm defect, it is usually better to make a *delay* (Figs 76, *D* and 77, *B*), partially severing the flap on the abdomen and raising it up a few days before the flap is completely severed and sutured to the arm In delaying a flap, it is advisable to allow extra skin, if not enough is taken and the defect has to be closed with tension, sloughing along the suture line and separation of the wound edges will be inevitable The best procedure is to make a pattern of the extra skin needed and mark it on the abdomen, allowing some excess The skin is then prepared in the usual way by cleansing and painting with antiseptics, and the patient is anesthetized The incision is made through the central two thirds of the line where the final incision will be The incision is carried down to the deep fascia, and the skin and fat are undermined up to the edge of the area where the back side of the flap hinges onto the abdomen Usually this area is considered to be contaminated and the incision is not connected to it if possible Bleeders are tied, drainage is instituted if necessary, and the skin is closed A few days later the patient is returned to surgery, sutures are removed from this part of the incision and the balance of the flap is then

abdomen and the pattern applied to the wound with one border held against the abdomen as a hinge The arm is removed and the pattern, still hinged on the abdomen, is flattened against the abdominal skin to give the outline of the flap to be elevated The outline of this flap is marked with a sharp knife, and an incision made through all thicknesses of skin and subcutaneous tissue down to deep fascia. The flap is then undermined in the layer between the deep and subcutaneous fascia back as far as the hinge All bleeders on the flap and on the donor site are picked up and tied, using the finest possible ligatures In tying bleeders on the flap, it is important to pick up only the bleeding point so that the blood supply of the flap itself is not compromised When the flap has been properly made it should fit exactly into the recipient site, without tension and without kinking, and the extremity should be comfortable

With hemostasis completed, the arm is placed against the abdomen and the flap is sutured into the defect, using half-buried mattress sutures (preferably of wire) along the skin edges The donor site may be closed with a split thickness graft, at times the surrounding skin can be undermined and the donor area closed directly, or the opposite ends of the donor and recipient sites sutured together to form a double-hinged flap It is much better to have a closed wound than to leave the area between the hand and the hinged edge of the pedicle open A certain amount of sepsis is bound to develop in these areas, resulting in fibrosis, contracture and delayed healing

The formation of a flap is not an easy matter to be accomplished in a few minutes, and the mechanics of properly locating the flap so as to fit the forearm require considerable imagination and some experience This method is not recommended for the occasional operator but may be a means of salvaging an extremity which otherwise would be extremely crippled With the advent of antibiotics, it has become possible to apply flaps on defects which are up to 24 hours old with a fair proportion of success It follows that, with modern methods of transportation, a defect may be partially closed by the physician giving first-aid treatment and the patient then transported to a center where there are more adequate facilities

Postoperative care of flap—Pedicle flaps supplied from the abdomen require even more postoperative observation than local flaps After the flap is applied, it may be necessary to pin the radius and ulna together at the wrist to hold the forearm in the correct amount of pronation or supination It is usually best to leave a few drains under the flap and also to drain the angle of the wound where the recipient side of the forearm

divided from the abdomen A common mistake is to allow too little skin for complete closure of the defect on the extremity This happens because the hand is lifted up from the abdomen, stretching the skin both ways and enlarging the apparent size of the flap on the arm as well as its attachment to the abdomen In these circumstances it is better to apply wet packs and to permit the wound to close by granulations than to attempt suture with the almost certain prospect of having the additional skin slough A flap that is properly cut should fit into the defect with just the normal amount of tension on the skin all along its edges When half-buried mattress sutures are inserted, there should be no blanching or other evidence of circulatory impairment

The foregoing procedures have their greatest applicability for losses of tissue on the dorsum of the hand or forearm, the ulnar borders or the radial border of the forearm or palm If positioning the hand for a palmar flap (Fig 77) is difficult, it is probably better to cover voids or defects with a split thickness graft to be replaced later with a tube

For the average operator the more complicated procedures, such as defatting the flap, using the fat as a pedicle to free tendons or threading tendons through the fat in the flap, should be done at a later date after the wound has healed kindly and all evidence of induration of the tissue subsided Eventually, the appearance of a flap should blend naturally with that of the rest of the arm

SOFT TISSUE DEFECTS OF DIGITS

CROSS-FINGER FLAPS —Whenever it is necessary to supply skin and subcutaneous tissue to a reasonably small area in the hand, a cross-finger flap or local rotation flap may be successfully employed (Fig 78, Plate 1) These flaps are exceedingly versatile but cannot be used for large areas and are usually not successful if the circulation is retrograde (*C*) Usually the donor area is covered with a split skin graft, and the fingers are temporarily fastened together with extra wire sutures A graft from a large finger to a smaller finger is easier than the reverse Flaps may at times be shifted from a partially amputated digit (Fig 78, Plate 2, *B*) Local rotation flaps shifted from the dorsal to the volar surface are a time-honored device but have not, in my experience, been of much use, usually a pectoral flap has been necessary where the cross-finger principle could not be used

The thumb is such an important member that it is well worth while to take a little skin from the side and dorsum of the index and long

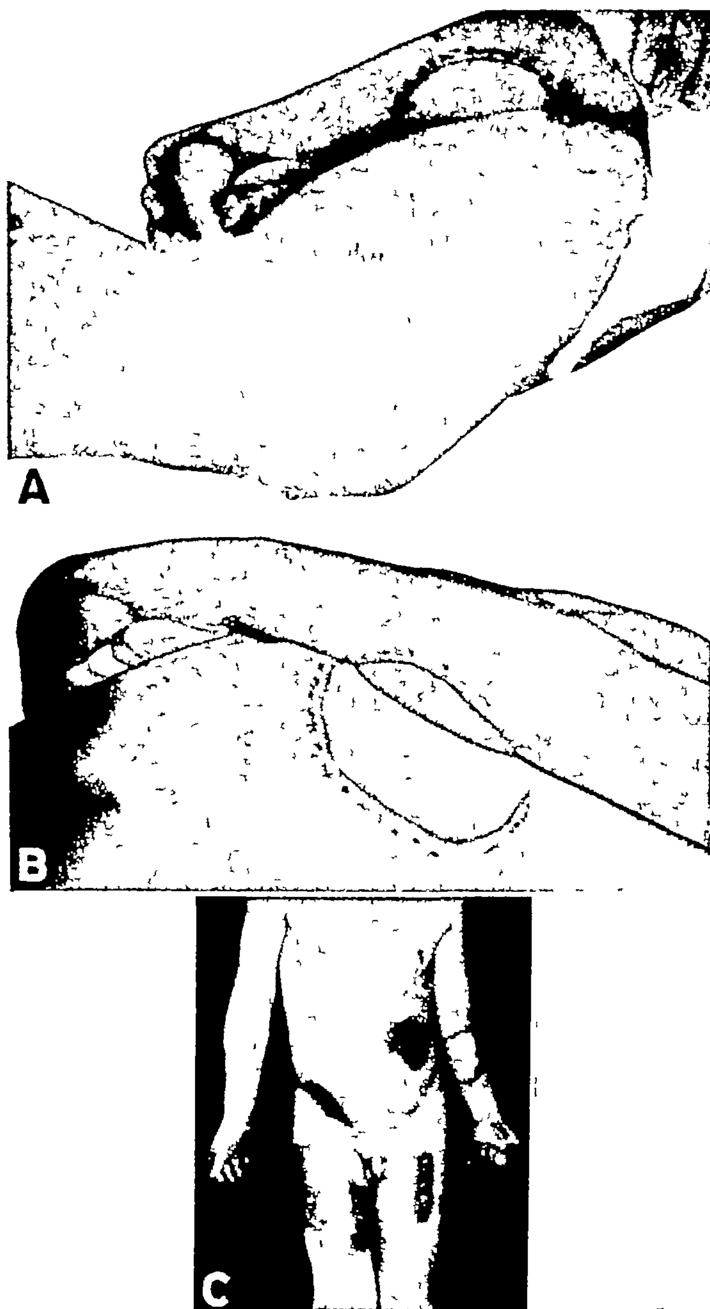


FIG 77 —*A*, two one-stage flaps applied simultaneously to front of forearm and palm following wringer injury *B*, delay incision to enlarge forearm flap *C*, result. Donor areas on abdomen were used for flaps, donor areas on thighs for skin grafts to close abdominal sites Gangrenous tip of thumb in *A* was amputated

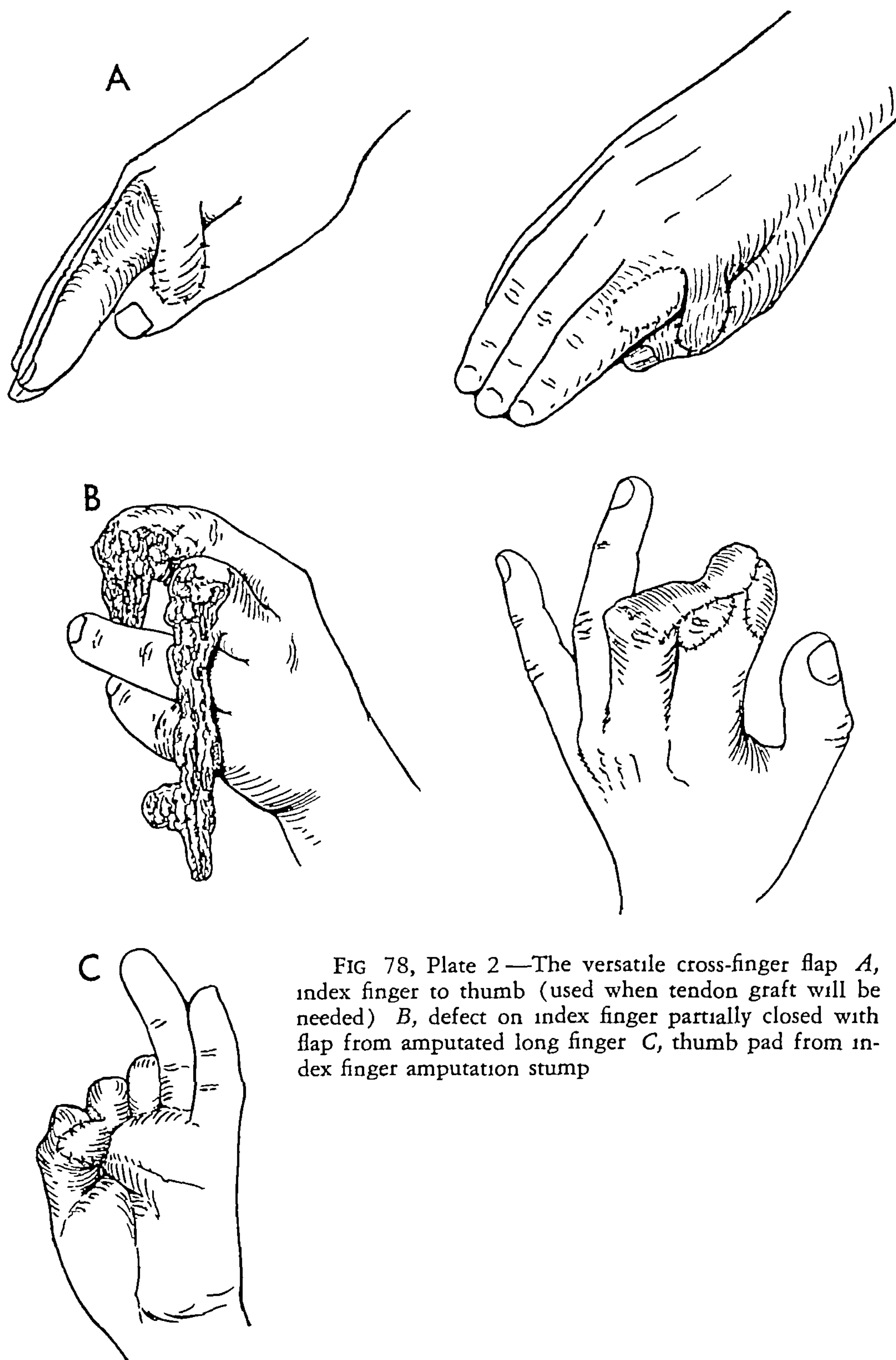


FIG 78, Plate 2 —The versatile cross-finger flap *A,* index finger to thumb (used when tendon graft will be needed) *B,* defect on index finger partially closed with flap from amputated long finger *C,* thumb pad from index finger amputation stump

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donor finger) *B,* index finger to amputated thumb tip *C,* retrograde flap, finger tip of little finger

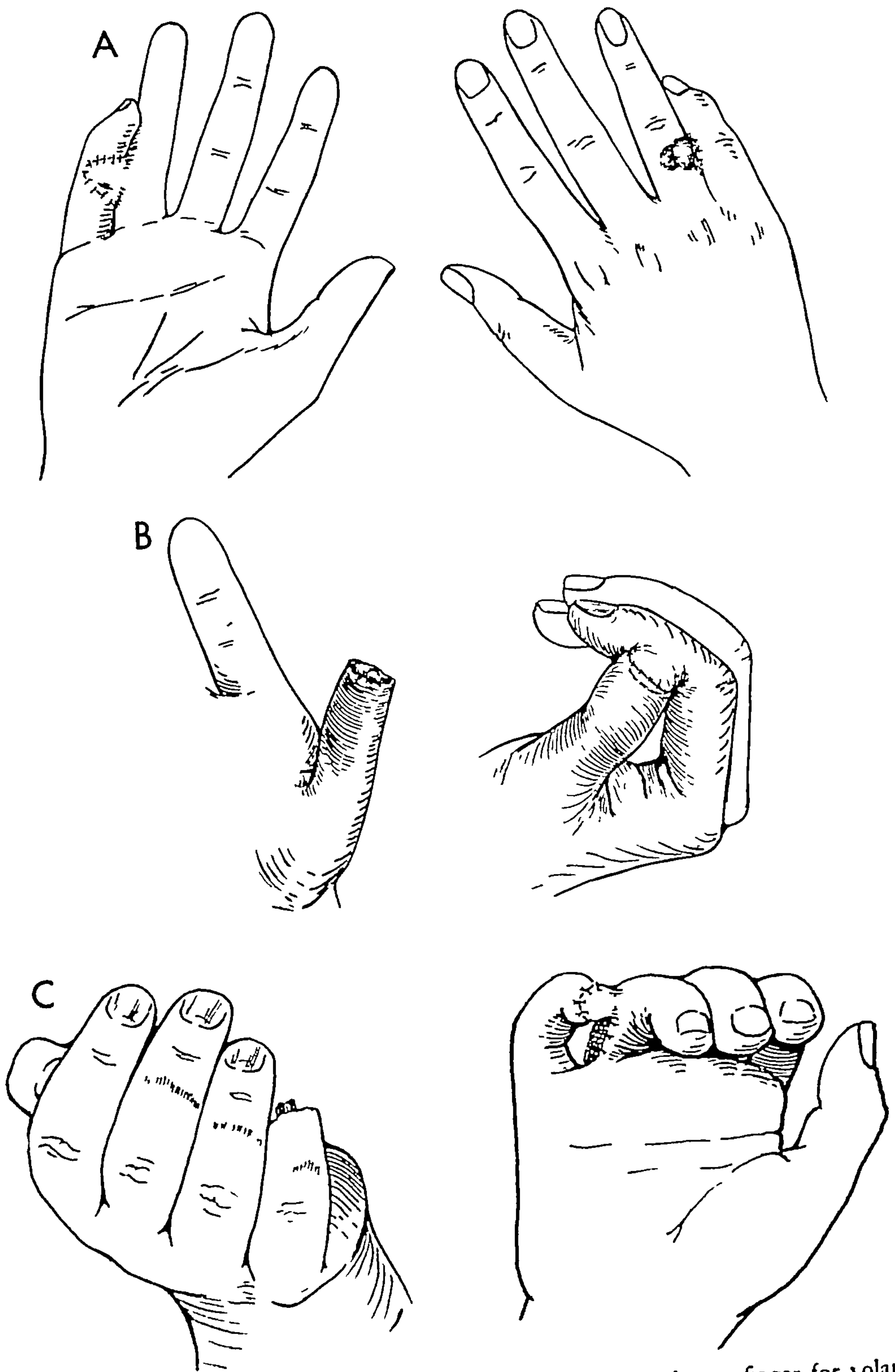


FIG 78, Plate 1—The versatile cross-finger flap *A*, classical cross-finger for volar defect in proximal segment of small finger (dorsal view shows split graft applied to

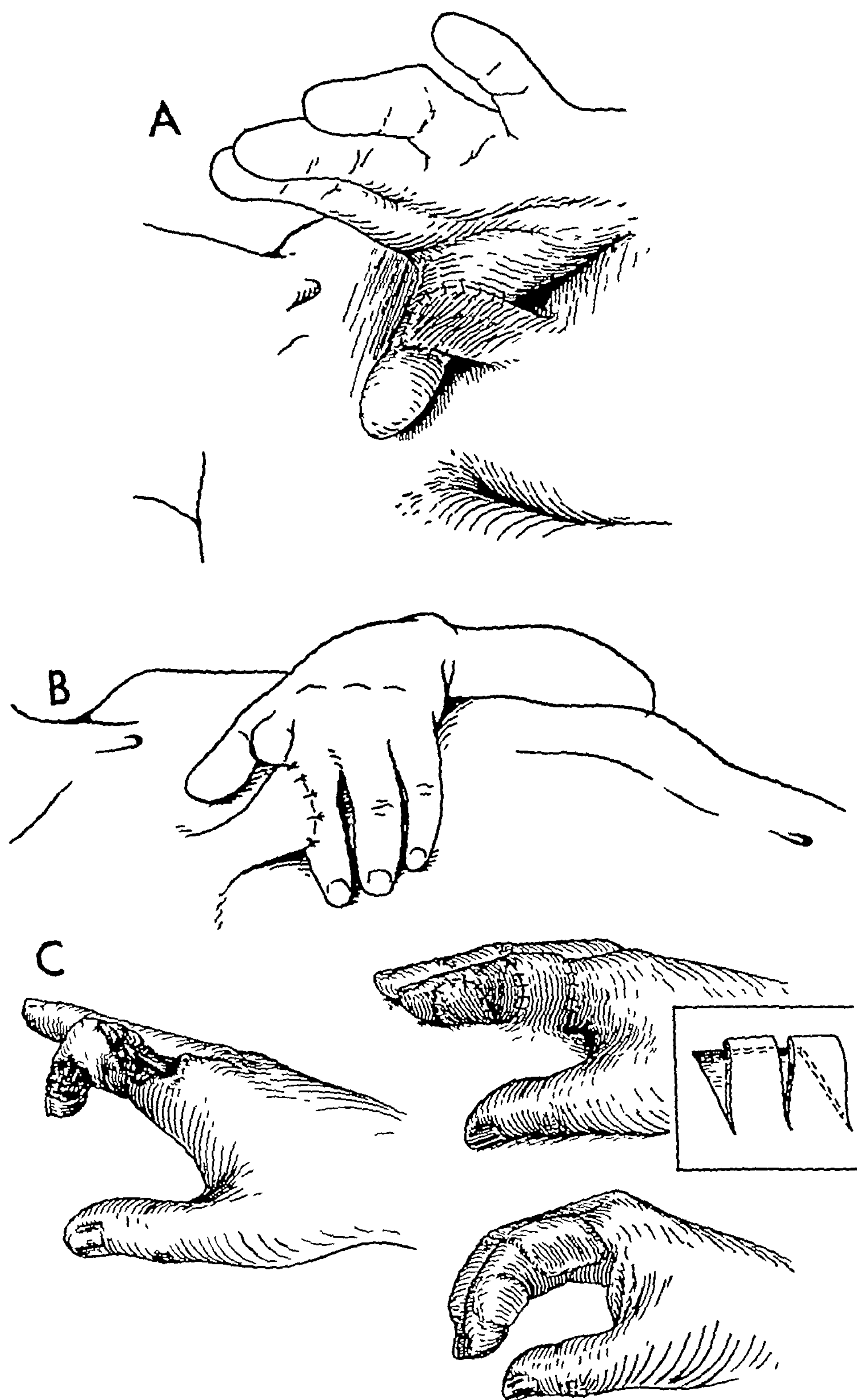


FIG 79 —One-stage pectoral flap *A*, flap to volar surface of thumb *B*, flap to proximal portion of finger (index missing) *C*, double flap to index finger (tendons exposed by power saw)

fingers to give length and padding to the thumb (*B*) The semilunar flap, based dorsally, is raised from the radial side of the middle segment of the index or long finger. The tip of the thumb is positioned against the open face of the turned up graft and donor site and sutured into place Two or three heavier sutures at the angles between the thumb and finger prevent its pulling loose, and after a day in the hospital the patient can be discharged as ambulatory After about three weeks the flap is severed from the index finger, allowing enough extra skin to cover well the bare area on the pad side of the thumb. The donor site is closed with a free graft This procedure is particularly useful when the thumb is cut off half way down the nail or farther Results of this method are good padding and almost normal sensation

ONE-STAGE FLAPS—Loss of the soft tissues over the distal segment of the finger sometimes occurs when the finger catches on a sharp object during a motor accident or a fall The entire pad of the distal segment may be torn away, leaving only the phalanx and nail. Axe wounds too may sever one half of the distal segment of the finger and may also open the distal interphalangeal joint If such defects are covered by a split thickness graft, the graft will lie directly in contact with the bone and an uncomfortable scar and considerable deformity and loss of use are inevitable A small one-stage flap is therefore often needed for these defects

The flap is easily raised from the opposite pectoral region (Fig 80) The entire denuded surface is covered with the flap and the wound is closed by suturing the proximal wound on the finger to the skin opposite the flap on the chest, undermining as necessary to get these edges together At the end of three weeks the pedicle is severed and some supplementary trimming done to get an accurate fit. The chief objections to this procedure are that the skin supplied to the tip of the digit is devoid of sensation for a prolonged period—a condition which the patient often finds very annoying—and that secondary pigmentary changes may occur which render the flap unsightly

Much more satisfactory areas on which to apply a flap are the proximal and middle segments of the fingers (Fig 79). This is the method of choice when a saw cut has amputated one or two fingers and the volar surfaces of the remaining digits are avulsed However, this type of flap may be difficult to apply and if one is in doubt a free skin graft should be used as a biologic dressing to be replaced later, using a Gillie's tube (Chapter 14)

REPLACEMENT OF TIP OF DIGIT—Occasionally, when the tip of the finger has been cut off, it may be successfully reapplied to the finger

unlike the fingers, stiffness is not so important, and any stump of bone that is present may profitably be salvaged To cover such a short stump it is necessary only to raise a squarish flap in the pectoral region The edges of the donor area are undermined and approximated, permitting the proximal corners of the flap to be sewed together The rest of the flap can then be brought together around the stump of the thumb (Fig 81) The procedure of removing the thumb bones and suturing the skin of the palm to the dorsum of the hand is mentioned only to be condemned

Sometimes patients are seen in whom all the digits have been avulsed, leaving the stumps of the proximal phalanges protruding, but destroying

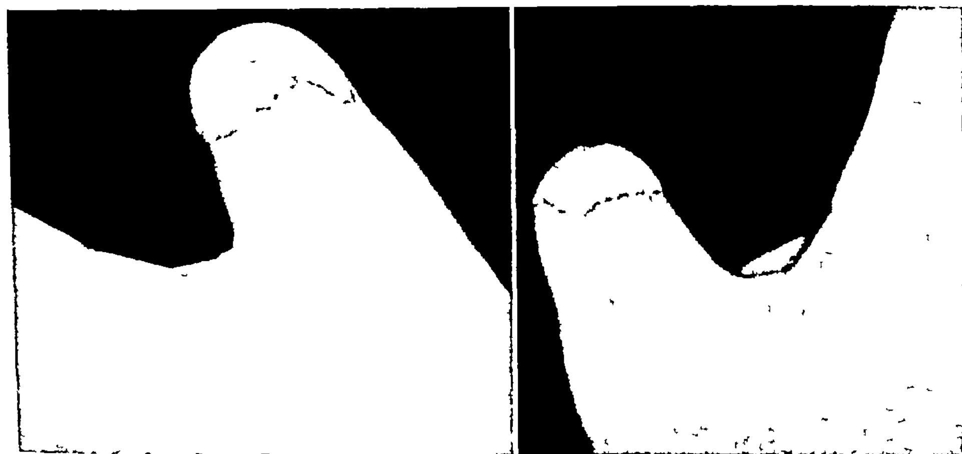


FIG 81 —End of thumb (lost in sawmill accident) replaced secondarily by pedicle after skin grafting Volar and dorsal views show proper insertion of flap edges to prevent contraction of scar (identified by ink dots)

all the skin beyond the distal palmar crease and exposing a good part of the metacarpals dorsally. There is no excuse for sacrificing the stumps of these phalanges, as is commonly done Many of these patients have had the distal palm together with the stump of the phalanges and the heads of the metacarpals amputated and the skin of the palm sutured to the dorsal skin The result is an unapposed thumb and a perfectly useless member In the next chapter some suggestions for the management of these cases are made

by suturing it back carefully after careful excision of all fat from the loose piece Some very complicated procedures have been devised to restore the end of the finger by fastening the denuded tip into the palm, applying the skin of the palm to the tip of the finger as a pedicle This procedure is not without its difficulties The thenar prominence is usually used as a donor area, and the joints are kept tightly flexed during healing, and some stiffness usually results When the palm is used as the donor site, the result may be a tender, painful scar and more disability than from the original injury.

TECHNICS FOR COMPLETE AVULSIONS—Sometimes all the tissues are avulsed from the finger by a ring which is caught on a protruding object during a fall Prophylaxis is the best treatment for this type of

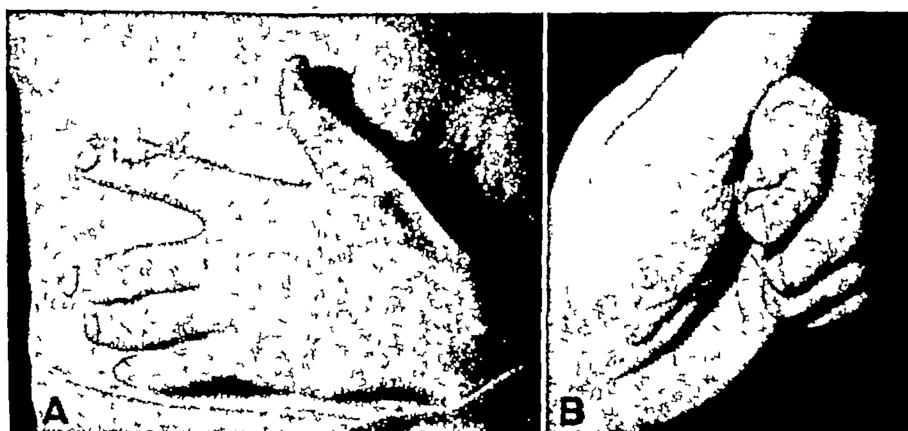


FIG 80—*A*, one-stage flap to index finger to replace tissues lost in Skilsaw accident. *B*, result

injury It is a great mistake for laborers, mechanics and others to wear rings while working The patient with such an injury should be told that the finger cannot be rehabilitated to anything like normal use Even if the tendons and joints appear normal, so much stiffening will occur during healing that the eventual result will not be satisfactory If the skin is only partially avulsed for a short distance, it can be partially reapplied and the inevitable defect between viable skin proximally and viable skin distally covered temporarily with a split thickness skin graft This split graft usually has to be replaced later with a flap

Defects on the backs of the digits usually may be successfully repaired with split thickness skin grafts Although some stiffening will be inevitable, often a functioning useful member can be obtained

Loss of the thumb constitutes a disaster to the patient In the thumb,

datory even if severance is complete Frequently the customary antero-posterior and lateral views cannot be obtained, but in any case studies should be adequate to show fractures or dislocations An attempt should be made to test the function of nerves and tendons, as such information may be useful during surgery, when the patient is asleep Information about nerve function thus obtained is equivocal, however Often the nerves of sensation are knocked out temporarily by the contusion, and temporarily paralyzed motor function may eventually return Usually skin which still has sensation is viable, although after loss of circulation sensation loss may not be immediate

The factor most important to surgery in these cases is the circulation When this is severely damaged the prognosis is hopeless, although a segmental loss may be repaired with the technics of present-day vascular surgery If the main vascular channels are badly damaged, collateral circulation in crushing injuries is usually inadequate Venous return is just as important as arterial supply, and compression of these channels frequently causes failure of repair Circulatory failure is more common in a crushed extremity than in one which is almost separated by a clean cut In the latter, if any circulation remains, the member can be saved

TREATMENT

Having made the recommended diagnostic tests and treated the patient for shock if it is present, the surgeon should prepare immediately for surgery, nothing is gained by procrastination Waiting for a line of demarcation or hoping that the circulation will return is not worth while Skin grafting by pedicle flaps or free grafts, repair of fractures or dislocations by internal fixation, or restoration of blood vessel continuity by suture or graft may be necessary

Crushing injuries tax the ingenuity of the most skilled surgeon The British call these cases "untidy" Nerve and tendon repairs are, by and large, worthless and contraindicated Devitalized muscle must be removed, and viability of what is saved must be assured A bone or joint may be salvaged by covering it with viable skin A common problem is that the bony framework is too unstable to support a covering of skin and the available skin of the extremity is inadequate The bony framework must then be covered using the pedicle-from-a-distance method, with intramedullary transfixion by Kirschner wires used to stabilize bones The surgeon should, of course, obtain the patient's permission to use pedicles or make an amputation as he sees fit and should make the patient understand the reasons for his choice

CHAPTER EIGHT

Crush Injuries

CRUSH INJURIES are closely related to avulsions in that the skin is usually burst open, torn away or otherwise devitalized In addition, there are complicating injuries within the hand, including fractures and less obvious but equally serious injuries to joints, tendons, muscles, etc The causes vary widely Crush injuries are common in logging and sawmill accidents and in accidents with punches, presses, triphammers, paper rollers and corn pickers

PATHOLOGY

Depending on the force inflicted, any degree of damage from simple contusions to complete severance is possible Even in the simpler cases (Fig 72, *C*), swelling of the hand occurs and is followed by stiffness and varying degrees of muscle atrophy and contracture A hand caught between rollers has multiple injuries split skin, squeezed-out muscles, dislocated joints and fractured bones A press or triphammer injury is even more severe and may result in immediate amputation of part or all of the extremity In some of these cases there may be only avulsion, with nothing lost but skin, in others amputation or compound fracture, and in many combinations of all three Whenever the injury extends into the forearm, as when an arm is drawn through rollers, muscle damage is severe even if not obvious, and a late contracture is thus explained

DIAGNOSIS

The obvious extent of the injury in these cases should not distract the surgeon from making his usual diagnostic studies X-rays should be man-

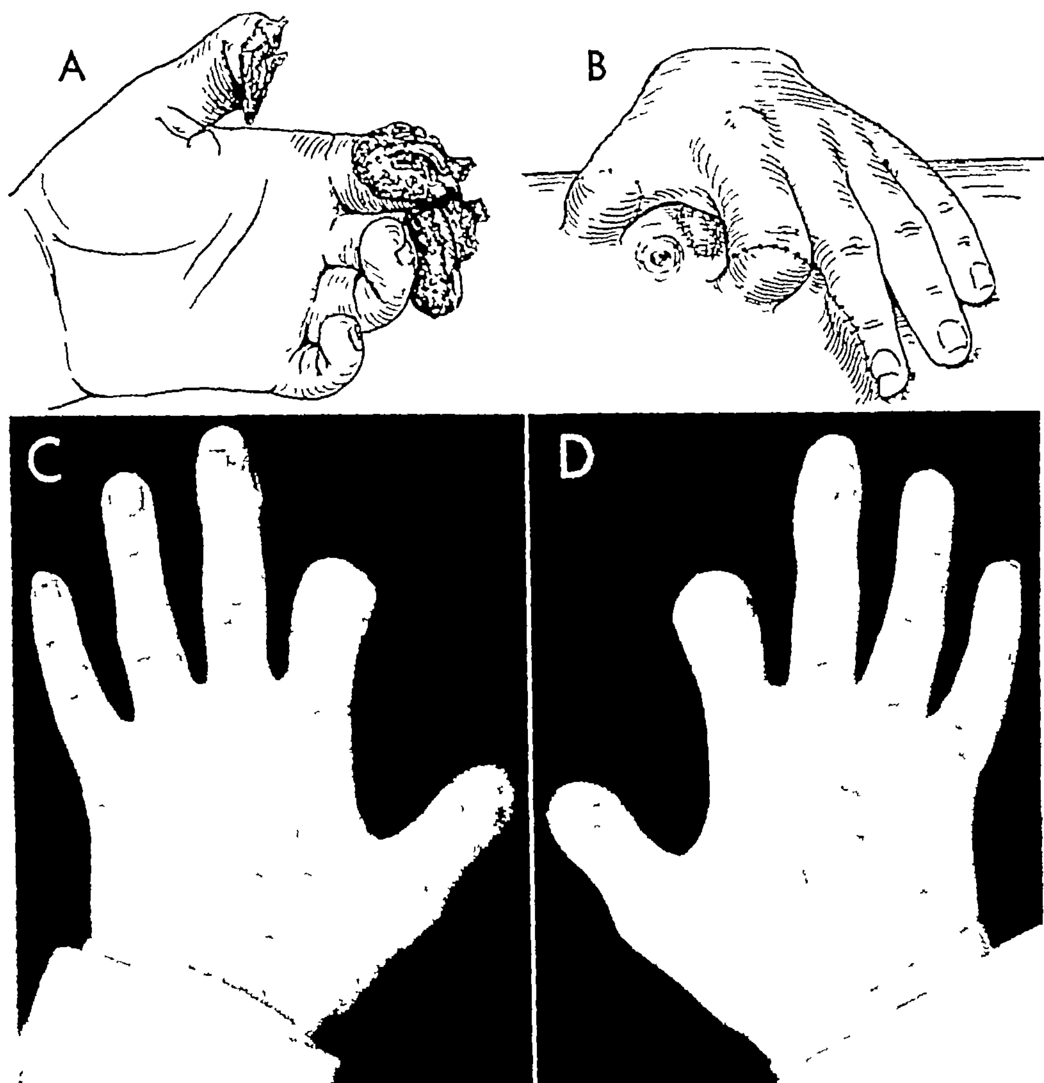


FIG 82, Plate 1—Degloving of digits *A*, degloved by explosives *B*, treatment by primary flaps *C* and *D*, result

TECHNIC

A full operative setup is necessary, and general anesthesia is usually best A tourniquet should *not* be used The skin is cleansed with soap and water or a detergent, and copious quantities of saline irrigate the wound The extremity is then draped, and devitalized tissues are removed after assessment of the circulatory condition

For simplicity of discussion the digits, palm and forearm are discussed separately

THE DIGITS —A crushing injury to a *single* digit, unless it be the thumb, is rarely worth repairing because the result is usually a member so stiff and mismatched that it interferes with the use of the rest of the hand If the *thumb alone* or *all the fingers* are crushed, some repair is mandatory and well worth the trouble

In simple cases, when both skin and bone are present and the skin is viable, repair is usually a matter of reducing fractures or dislocations, maintaining reduction by transfixion pins or by position-of-function splints and closing the skin wound loosely with interrupted sutures Skin grafts should be used if necessary to secure closure

In the degloving type of crushing injury caused by explosives or rollers (Fig 82, Plates 1 and 2), the protruding phalanges may profitably be covered by burying them in the abdominal wall and securing full coverage later by migrating additional skin to their volar surfaces with the delayed pedicle method The procedure is chiefly indicated for covering proximal and middle phalanges when their joints and tendons are intact and the rest of the hand is all right Longitudinal fractures in the protruding bone segment are managed by encircling wires Sharp spicules at the tips of bones are best removed

Treatment is in stages, and for this reason the surgeon is cautioned against using it on elderly patients, whose shoulder and elbow joints stiffen easily At the first stage the protruding bone ends are buried in the abdomen or chest, with the fingers separated as widely as possible (Fig 82, Plate 2, *A* and *B*) In several subsequent stages incisions partially free the skin covering the dorsum of the bones and later free additional skin, which will be brought around onto their volar surfaces Finally, the hand with the attached flaps is freed, and the skin flaps are brought around onto bare volar areas Great caution is needed at this stage, as any angulation of a flap may cause gangrene The pedicle skin may be wrapped around the end of the stump or from side to side

Results of this procedure have been gratifying in a number of personal

vascular damage and gross soiling The surgeon will often have to excise and amputate piecemeal until he comes to viable tissue, as the small arteries and veins in the hand cannot be repaired Straightening things out may untwist a vessel and restore circulation but cannot be expected to rejoin separated vessel ends While it is temporarily satisfying to restore the bony framework with Kirschner wire skewers, it should be borne in mind that the blood to the digits is carried in vessels invested by the skin Consequently, if the skin is torn away at the base of the finger the digit is usually nonviable, unless there are intact vessels in the depths of the wound Replacing a cold, gray, pulseless digit, even in the presence of intact tendons and bones, usually will be followed by moist gangrene and infection which invites disaster When in doubt it is better to make small incisions in questionable tissue to see if active bleeding will occur

After debridement the bony framework is accurately repositioned and held with transfixion of wires, using intramedullary pinning and crossing joint surfaces if necessary to keep the fixation solid but simple Securing adequate cover for the parts has been discussed in Chapter 7 Certain points, however, deserve emphasis

Crushed skin is of much lower viability than skin which has been torn off in some other way, and a crushed hand is much more susceptible to infection Sometimes it is better to sacrifice a few bony structures to get good skin cover than to try to save everything and end up with a whole but useless hand When enough bony framework can be salvaged and covered with skin to construct a functioning pincher, an operation to accomplish this result is worth considering When pedicle skin covers everything to the wrist, about the most that can be expected is active spread amounting to about 1½ in and firm pinch between the ends (Fig 83) This is better than an amputation with a prosthesis because the wrist joint, with pronation and supination, is preserved Tactile sensation is never very good, but proprioception is good and learning to use the pincher presents no problem

Results of secondary tendon repairs after severe crushing injuries are discouraging, as usually the joint damage and soft tissue injury is irreversible Figure 158 illustrates the type of result that can be anticipated

THE FOREARM —Crushing injuries of the forearm, like those of the fingers, require evaluation before salvage is justified If the hand, fingers and forearm are crushed but circulation to the fingertips is intact, the extremity is worth saving If injury about the wrist is severe, repair by shortening the bones to improve function of the hand may be justified

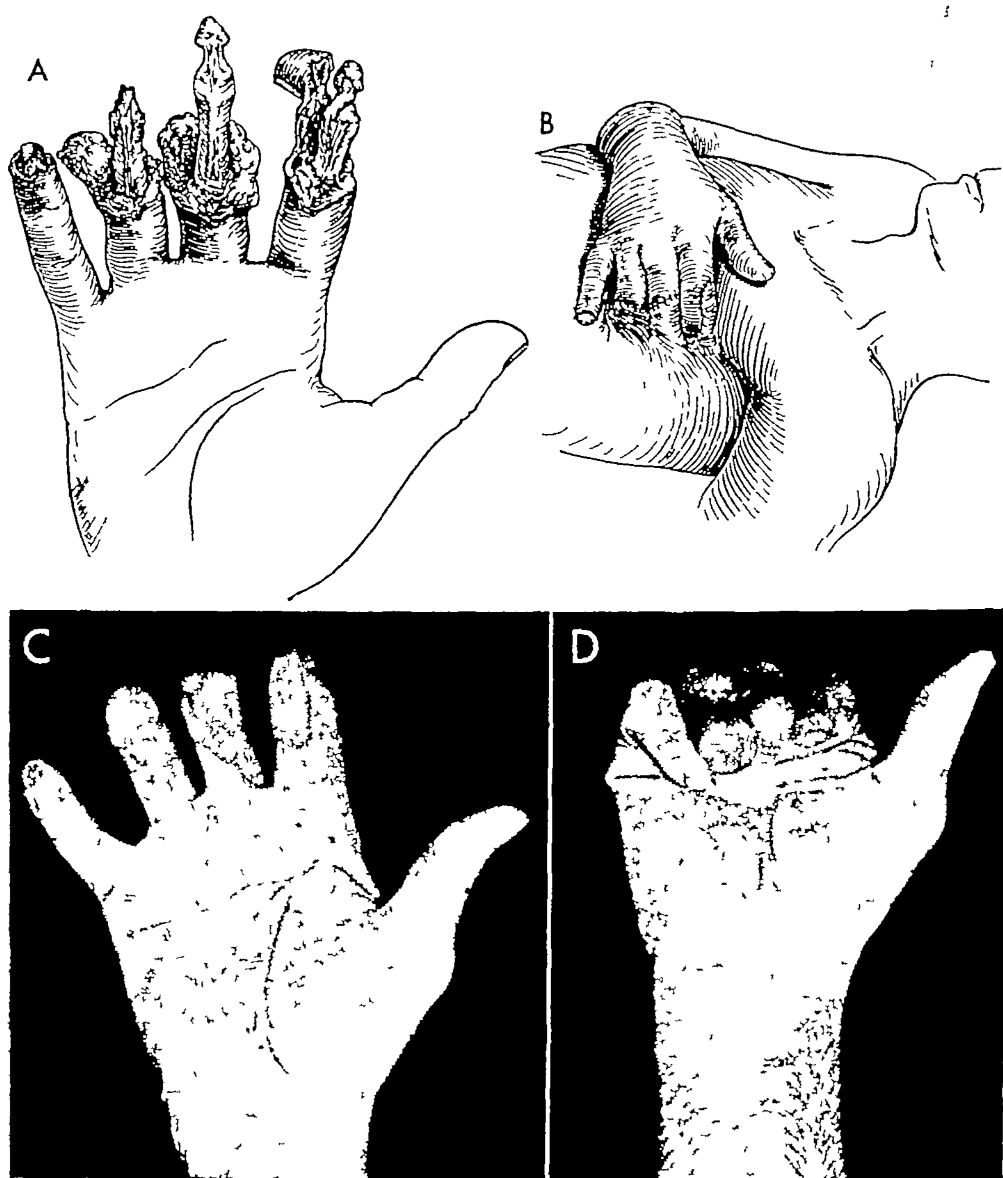


FIG 82, Plate 2 —Degloving of digits *A*, degloved by roller *B*, treatment by burying digits (see text) *C* and *D*, result.

cases (Fig 82, Plate 2, *C* and *D*) The short segments of the pedicle skin wear well and have fairly good sensation

THE PALM —In some palmar crushes the original tissue can be repaired, perhaps with amputation of one or two digits If the original tissues cannot be repaired, an attempt must be made to make some sort of substitute Most serious palm and wrist injuries are a combination of skin avulsion, open fractures and dislocations, and varying degrees of

This procedure is also indicated in cases with vascular damage The presence of one or more fractures makes this procedure more inviting, as the shortening of the bones to bring the parts together also simplifies management of the fracture The primary concern is vascular integrity, and, whatever procedure is carried out, the success of vascular repair is



FIG 84, PLATE 1—Crushing injury of forearm with loss of circulation treated by vein grafts and intramedullary rods with eventual failure of vein grafts

paramount Having attempted to restore vascular continuity by vein grafts (Fig 84, Plate 1), I am convinced that sufficient bone shortening to perform end-to-side arteriorrhaphy is the only successful method to save an extremity with both arteries cut Arteries are much more apt to be damaged in a crushing injury than are nerves or tendons, and a strip of skin containing intact veins will often be present If these conditions are encountered the following technic* can successfully be used

Tissue is widely debrided, and enough of each end of fractured radius

* Presented at the January 1958 meeting of the American Society for Surgery of the Hand

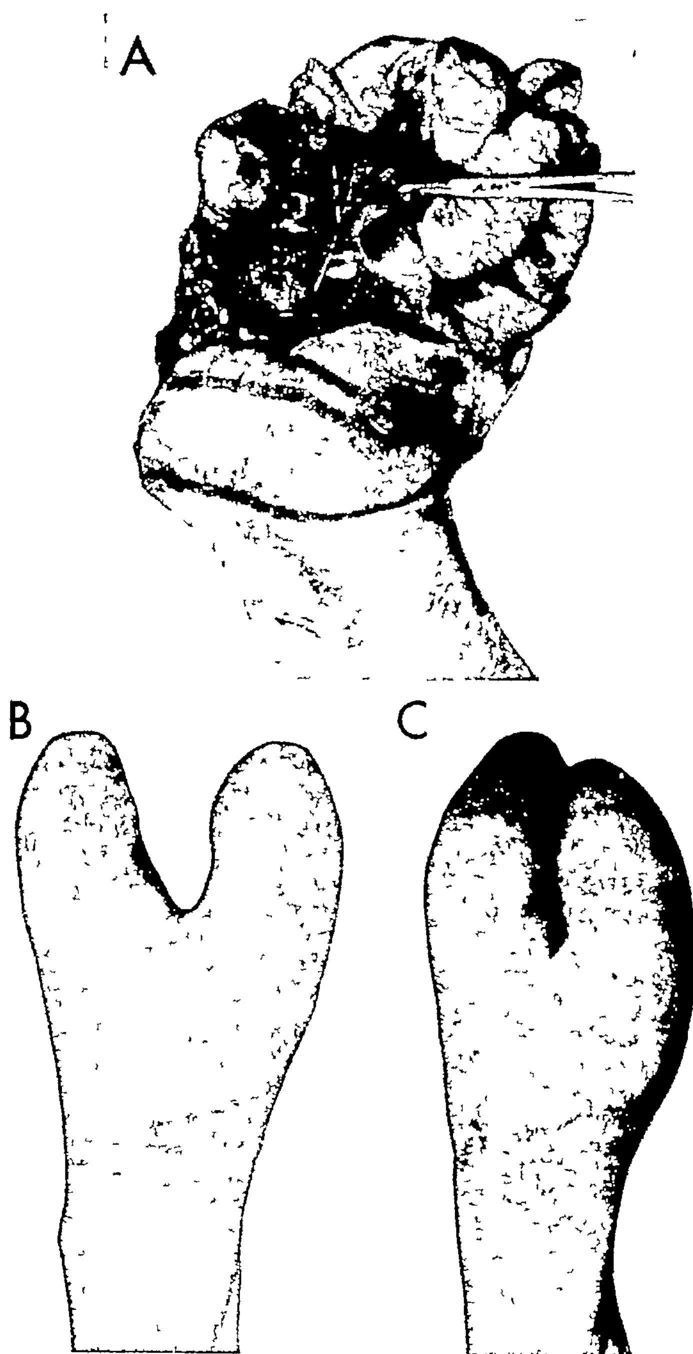


FIG 83 —*A*, hand crushed by falling timber *B* and *C*, result after treatment by complete resurfacing

and ulna is removed to give nice apposition of skin and soft tissues The proximal and distal ends of the radial and ulnar arteries are identified and distal arteries washed out with heparin solution, perfusing them to remove clots from the arterioles and venules Circulation proximal to the severed ends of the arteries is controlled by rubber-shod clamps The distal ends of the arteries are ligated and the proximal ends brought up to obliquity A longitudinal slit is then made in the side of the distal ends, and the arteries are joined end to side, using a suture of 6-0 arterial silk (Technic described by Robert Linton of Boston) It is not practicable to join the arteries end to end either by suture or by using the smallest Blakemore tubes Arteriorrhaphy using vein grafts over Blakemore tubes is technically feasible but places the graft at the point of maximum tissue damage where it has the poorest chance to survive Therefore, in selected cases, shortening the forearm by about 1½ in to overcome gaps in vital soft-tissue structures may be the procedure of choice This will allow vessels to be anastomosed rather than bridged by grafts (which may necrotize) and allow nerves to be united If the ulna is intact, its distal end should be resected and the radius shortened at the fracture

This procedure should also be considered whenever there is a loss of skin as well as tendons, nerves and bones at the wrist Often these problems can be adequately overcome by a skin graft, using local rotation flaps, free grafts or pedicle grafts Definitive surgery on tendons and nerves follows later But in appropriate cases the bone-shortening procedure gives better results than the more complicated and tedious one of pedicle flap application Presence of a fracture may be the deciding factor against a flap Osteotomy and removal of bone or removal of more bone at the fracture site may enable satisfactory approximation of the soft tissues and obviate the use of flaps and grafts (Fig 84, Plate 2)

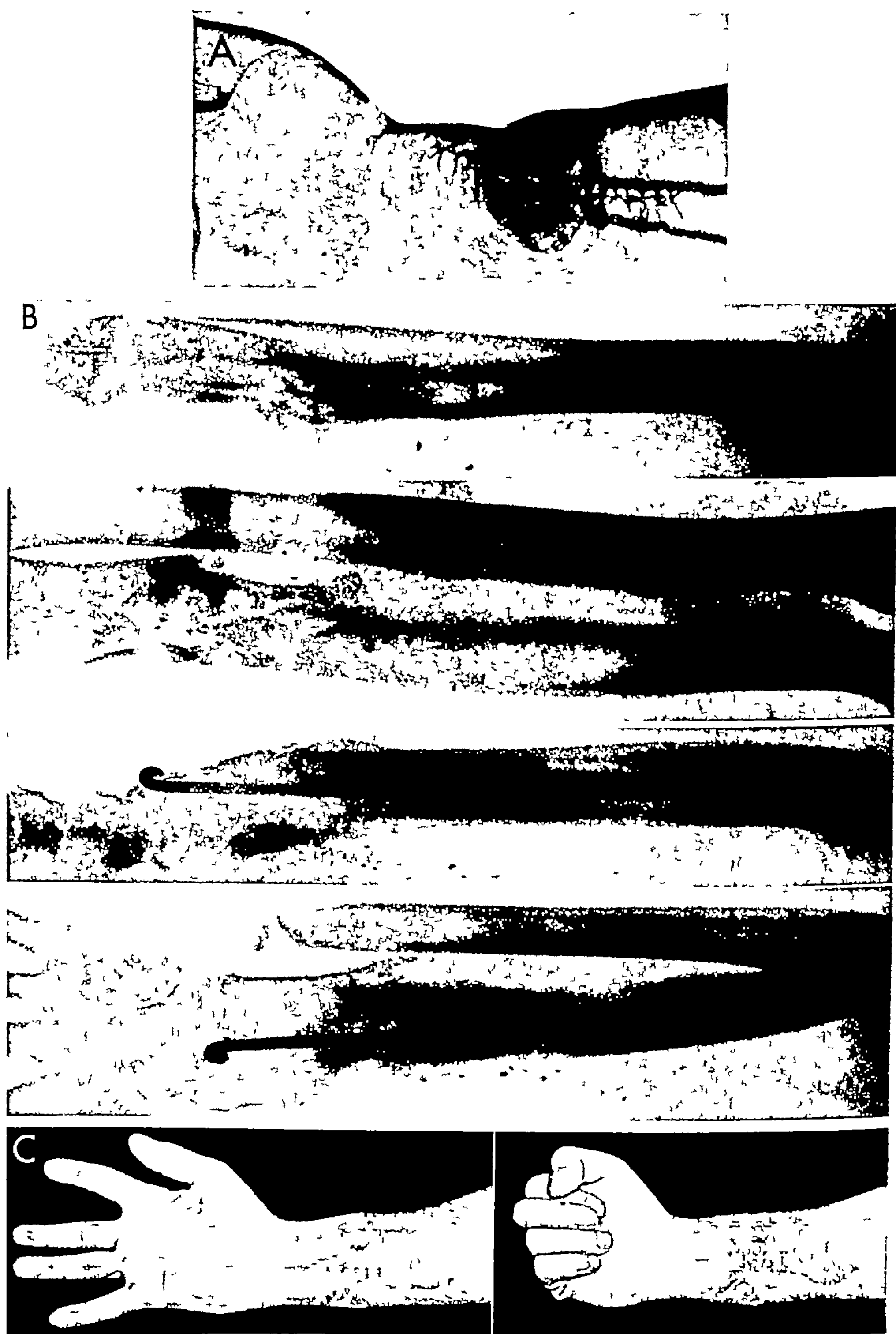


FIG 84, PLATE 2—*A*, Gunshot injury with loss of bone, flexor tendons and median nerve, treatment by shortening forearm 2 in , *B*, x-rays show injury and repair; *C*, functional result.

appear in the lymph, and these are gradually replaced by cicatrix. Within a sheath, the lymph reaction extends along the sheath and adhesions often form throughout the sheath, especially distal to the point of injury. The cicatrix that appears at the end of the tendon attaches itself not only to the other tendon end but also in tentacle fashion to whatever raw or injured tissues are present. When these happen to be bone or fixed fibrous septa, the tendon becomes anchored to these structures. Once bound down to bone or sheath it cannot free itself. On the other hand, if surrounding tissues are loose and movable, such as the loose fat in the forearm, the healed tendon will drag them back and forth and gradually increase its excursion by freeing itself from the surrounding tissues.

It has been shown experimentally that after repair a tendon is at first quite soft. As it heals, it gradually increases in strength, especially after the organized fibrous tissue begins to differentiate. This differentiation is not complete for several weeks. The collagenous connective-tissue fibers of the scar gradually become larger and blood vessels are squeezed out. When a tendon has finally healed, the point of union is a dense white scar which usually can be detected but which often is quite like normal tendon. The situation here is somewhat analogous to the healing process in a fractured bone.

After proper healing, the tendon must be stimulated by function to become smoother on the outside and less adherent to its surroundings. Frequently in severe wounds an excessive amount of scar tissue is laid down, binding the tendon to all the surrounding structures, including nerves, fibrous septa, blood vessels and bone. Under this condition little or no movement is possible and no amount of functional stimulus will free the tendon. Even when a repaired tendon lies adjacent to a normal tendon and works in co-ordination with it, such as the two flexors in a finger, it will be found to have become adherent to the adjacent normal tendon.

Animal experiments and clinical observations have now established the fact that *too early motion increases fibrosis* and is incompatible with proper healing of tendons. During the first five days of exudative and fibrinous reaction, the tensile strength of the union decreases. During the next 10 days, fibroblastic elements appear and the tensile strength of the union gradually increases. Motion during either of these phases increases fibrosis generally, the end result being to bind the tendon down rather than to free it. After fibroplasia is complete at about three weeks, motion tends to free the tendon, and as maturation proceeds the tissues should approximate normal. Even after three weeks the suture line is not too strong, and partial or complete separation may result from a sudden strain

CHAPTER NINE

Tendon and Muscle Injuries

TENDON INJURIES

OF THE VARIOUS mesodermal tissues of the body, tendons present the most complications in injury and repair Successful tendon repair is dependent on a combination of factors involving skilful technic, fine judgment in selection of cases and the location and extent of the wound

PATHOLOGY, PHYSIOLOGY OF REPAIR —A normal tendon consists of strands of fibrocollagenous material arranged like an untwisted cable It is relatively acellular and has a precarious blood supply (see Fig 3) It is covered with a single layer of very thin, flattened cells

Degeneration —When a tendon is contused, torn or cut the fibers fray out like the end of a rope Following injury, the normal white, shiny appearance of the tendon gives way to a dull yellow, and swelling appears either from infection or trauma This is particularly true after suturing *Ensheathed tendons,* when severed, retract and the ends may either become rounded and lie loose in the sheath or, more commonly, swell and become attached When an ensheathed tendon swells, apparently at times it becomes strangled by the sheath and is replaced by scar tissue *Outside the sheath* the paratenon which invests the tendon prevents excessive retraction and the tendon rarely degenerates or becomes caught in scar tissue for any great distance following injury

Healing —Whenever a tendon is injured a fibrous tissue reaction occurs and the reparative process makes no distinction between the tendon and its surroundings Lymph is at first poured out, cellular elements

for the sublimis tendons in order for the fingers to extend and flex fully. These studies exclude wrist motion which may amount to another inch (Table 2). Experience with the hands of paraplegics shows that, if the wrist flexor and extensor muscles are functioning, grasping can be restored by tenodesing the digital tendons proximal to the wrist Motion of the wrist then makes the digits move, provided there is free excursion of the tendons distal to the wrist In most locations flexor tendon repairs demand not only restoration of continuity but preservation of sliding in order to

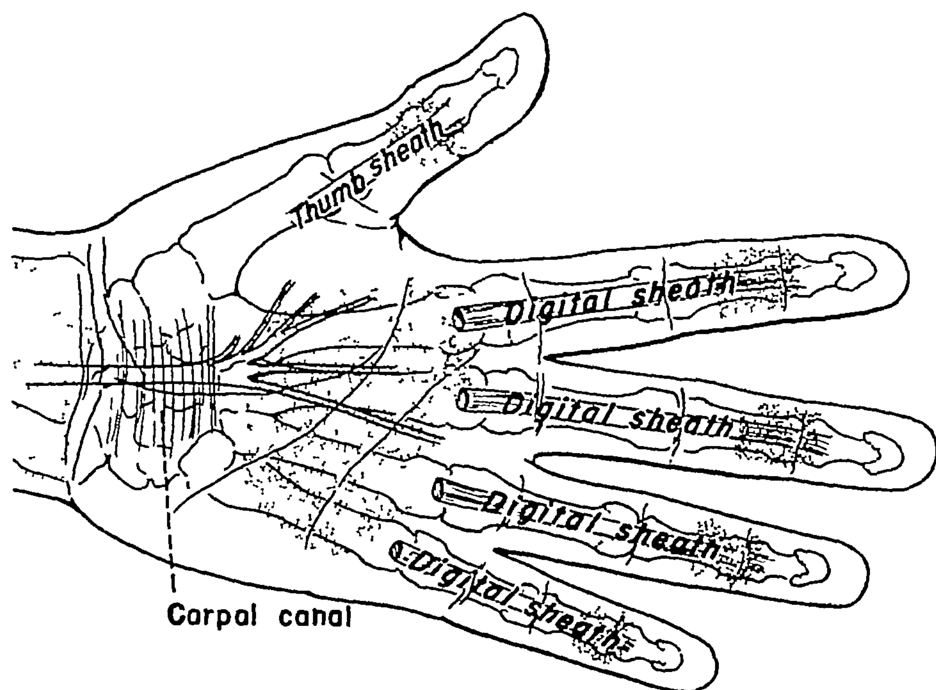


FIG 85 —Approximate locations of tendon sheaths and carpal canal Stippled areas show most favorable sites for primary repair (From Nichols Northwest Med 48 327, 1949)

restore function Figure 85 shows diagrammatically the favorable locations for primary tendon repair

CONTRAINDICATIONS TO PRIMARY REPAIR —Only in cleanly incised wounds without damaged tissue may tendons ordinarily be repaired If the wound edges are tattered, the skin hanging loose may better be sacrificed One fundamental rule is that if there is not sufficient viable skin to allow easy, tensionless closure of the wound, the tendons should *not* be repaired because the skin edges will slough, the repaired tendons will become exposed and the repair will be a failure In this situation, the wound should be closed by the best means available, using a loose

FACTORS IN SUCCESSFUL REPAIR —To a great extent, the relative success or failure in tendon repair depends on the location and type of injury Good results are obtained in the advantageous locations if the tendon ends are joined together with a minimum of trauma, using the least possible amount of suture material that will hold them together Use of *stainless steel wire* suture material is probably preferable for the average surgeon because it is nonirritating and of high tensile strength Because wire is more difficult to handle than silk or cotton, the latter substances have their advocates Catgut should never be used because it often acts as an irritating foreign body many months after it is inserted

TABLE 2 —EXCURSION (IN INCHES) OF TENDONS IN HAND AND WRIST
Fresh adult female specimen

	Little Finger		Long Finger
Hand *			
Flexor profundus	1¼		1¾
Flexor sublimis	1		1¼
Flexor pollicis longus		1	
Extensor digitorum communis		1	
Extensor pollicis longus		¾	
Extensor pollicis brevis		¼	
Wrist †			
Flexor carpi radialis		1	
Flexor carpi ulnaris		1	
Extensor carpi radialis longus		¾	
Extensor carpi radialis brevis		¾	
Extensor carpi ulnaris		¼	

* For excursion of digital tendons proximal to wrist add about 1 in
† Wrist tendon excursion measured without radial or ulnar deviation

Much better function is obtained after extensor tendon repairs than after repair of flexor tendons A number of diverse factors contribute to this (1) Extensor muscles are weaker than flexors, hence their tendons are less apt to pull apart during healing (2) Except for the short sheath on the back of the wrist, extensors throughout most of their length run in paratenon which gives a better blood supply and allows motion (3) Even with poorly functioning extensors, the hand works well By extending the wrist, grip can still be accomplished by the powerful flexors even if the extensors are checkreined by adhesions. Also, when the extensors are not working at all the patient learns to compensate for the disability in much the same manner as a person who has a radial nerve palsy with wristdrop (4) The excursion of extensor tendons is less than that of flexors

Any grasping motion requires active sliding of the flexor tendons. Studies on freshly amputated hands indicate that the finger flexors need to move about 1½–1¾ in for the profundus tendons and at least 1 in

tures are injured than was shown clinically Passive flexion or extension of the fingers will make the distal tendon ends appear in the wound. The distal cut ends, when found, can be identified by seeing which structures

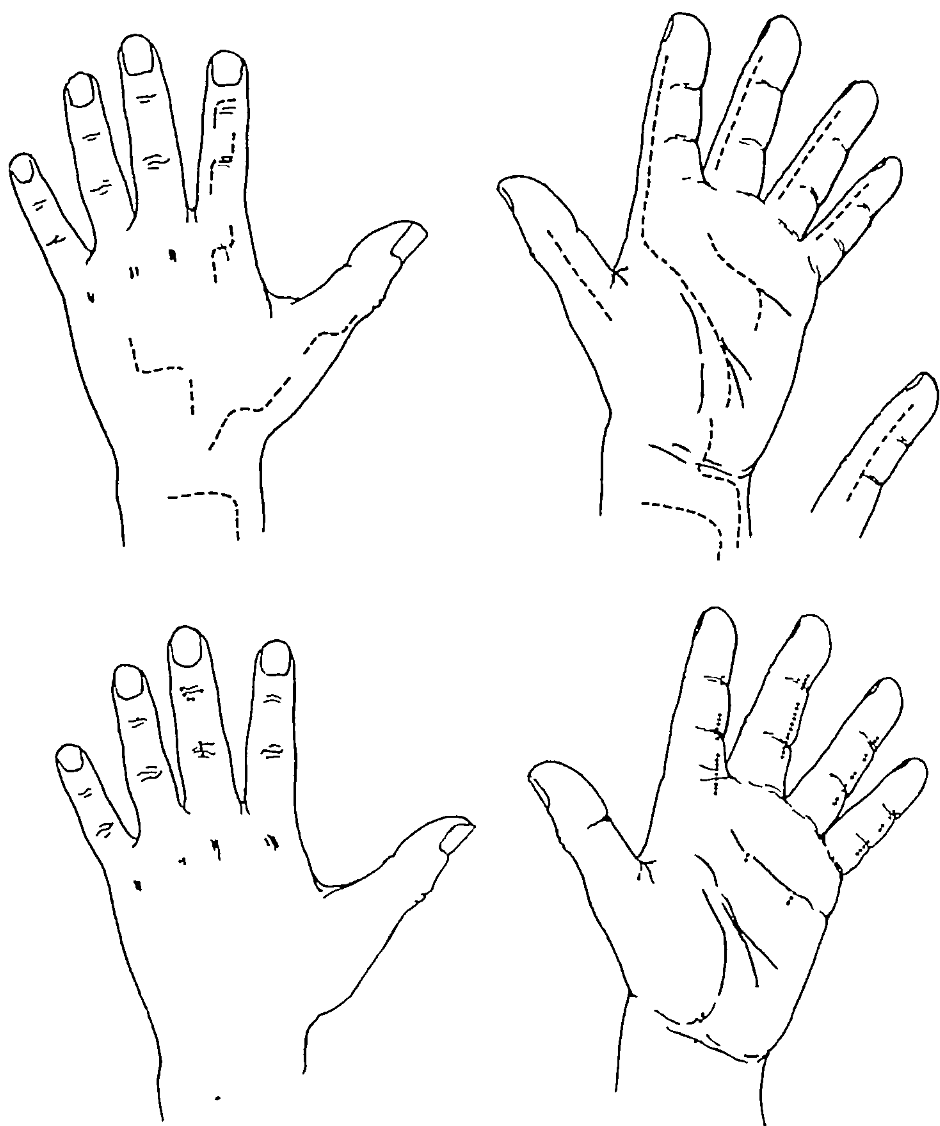


FIG 86—Surgical approaches to tendons on dorsum and palm of hand *Top*, correct, and *bottom*, incorrect incisions

they move A properly made incision in the deep fascia in the axis of the limb exposes the proximal end of the tendons and decompresses the wound after the repair, allowing healing under improved conditions The proximal tendon ends, as they are recovered, may be tagged with temporary sutures inserted about 1½ in from the severed end or held from

suture or a skin graft if necessary At times the avulsed skin may be used as a graft, as described in Chapter 7

Most successful repairs are located where sliding is not necessary or where the tendon repair is surrounded with tissues which will allow sliding Obviously, compound fractures, bare bone or torn tendon sheath with extensively traumatized tissues will inevitably bind the tendon and prevent sliding

Before the advent of antibiotics it was customary in many clinics to place a six hour time limit for primary repair in hand injuries If the tendon repair could not be done within this time, the proper treatment was to close the skin and to wait one to several months before doing a secondary repair With use of antibiotics, this time limit may be extended, provided the injured tissues have been properly protected and do not appear grossly changed * On the other hand, even in injuries within the time limit, the appearance of a dull, angry, unhealthy wound may be an indication to avoid primary repair There is also the factor of the causative agent, a bite, for instance, or a barnyard injury is much more apt to give trouble than a knife wound or a machine shop injury

When the proper surgical facilities for a primary tendon repair are not available, there should be no hesitation in closing the skin wound and making the tendon repair about a month later

General Technic of Repair

With the conditions presumably met for an ideal suture—preferably within six hours in a clean wound and with a good hospital setup—the surgeon must be willing to take time to perform the indicated repair The operating room routine which is described and illustrated in Chapter 2 should be followed The wound should be completely debrided and repair carried out in a bloodless field using atraumatic technic Anesthesia may be local or general

Incision —It is often necessary to make a surgical extension of the traumatic wound In general, skin incisions should never run straight across joints or be placed so that they will later interfere with the function of the hand (Fig 86) They should follow natural creases or be midlateral in nonmoving areas The deep fascia may be divided as necessary in the axis of the extremity

Identifying structures —It will often be found that more struc-

* M L Mason uses a time limit of four to six hours on most tendons and on flexor tendons two hours

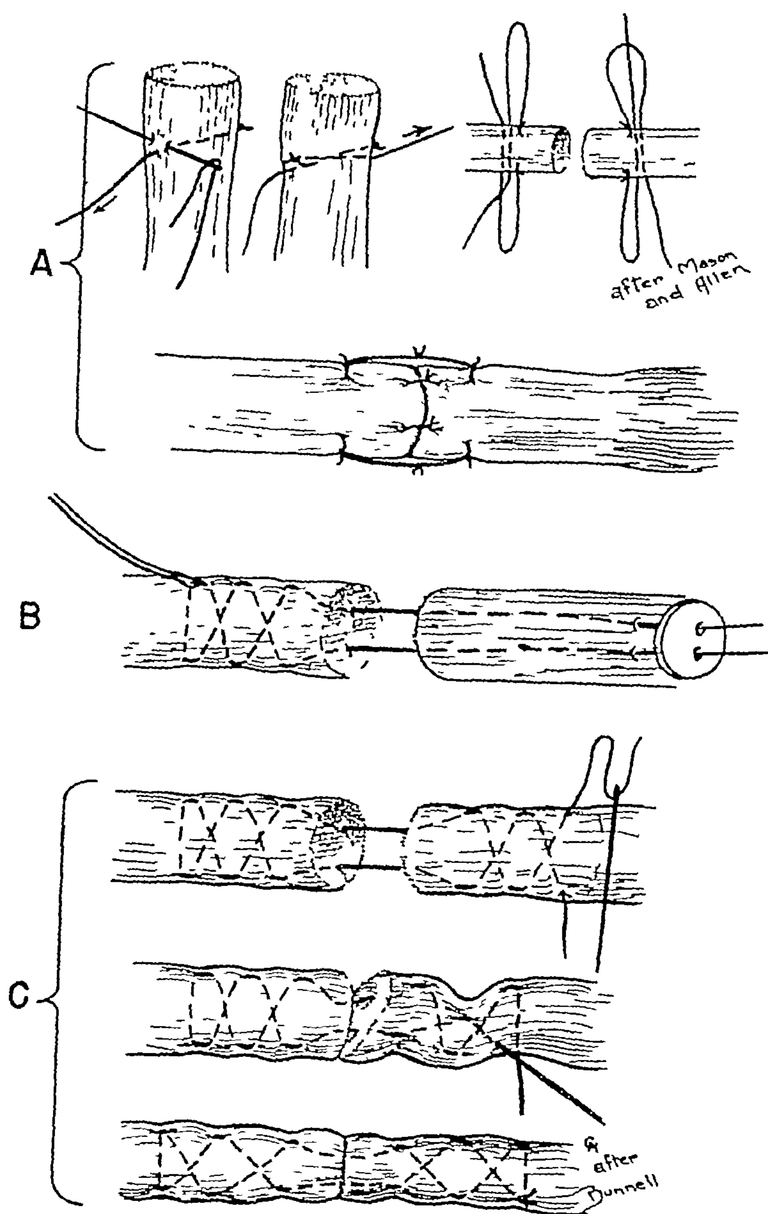


FIG 87 —Types of tendon sutures commonly used *A*, external stitch (Mason-Allen), *B*, pull-out technic (Bunnell), *C*, buried core stitch (Bunnell)

stitch was inserted in each tendon end and the tendons joined by tying the sutures together. This placed the knot at a point where it would inter- fere with healing At present most surgeons use only one suture which passes through both tendon ends, placing the knot away from the juncture

For this method, both ends of a no 36 stainless steel wire suture about 12 in long are threaded on fine, straight, cutting-edge needles The stitch

retracting by transfixion with a fine needle These measures aid in handling the tendons during the repair and avoid repeated trauma from forceps The repair should not be undertaken until all the tendons and nerves have been identified and matched

TENDON SUTURING—Tendons should be repaired before nerves, and deeper tendons before superficial ones If a good approximation is possible by a simple core type of suture, no further suturing is necessary If the tendons are fairly cleanly severed, it is probably superfluous to trim away the ends more than just enough for good approximation Oblique tendon ends that are not frayed need not be cut off squarely If frayed or otherwise damaged, the ends should be cut away with one stroke of a sharp scissors or knife All tendons should be repaired if circumstances permit, and no substitutions or variations from the normal should be made at a primary repair

It is important to avoid traumatizing the thin layer of epitenon or clamping or crushing the tendon ends The ends should be brought together as accurately and firmly as possible One or two approximation sutures may be placed right at the tendon juncture, but no more suture material than is necessary should be used here

Two general types of sutures are used (Fig 87) One is an exterior or surface suture described by Mason and Allen The other is the core stitch which may be either a simple mattress suture or the more complicated and better criss-cross Bunnell suture

External suture method—This method of end-to-end tendon juncture places the connecting strand of silk or cotton on the outside instead of inside the tendon and transmits the longitudinal pull of the suture as a transverse compressing force Two needles and two sutures are used, starting on opposite sides of the tendon (Fig 87, *A*) Each needle is passed through the periphery of the tendon about ½ in back from the cut end, picking up a small bundle of fibers above which the suture is tied Each needle is then directed through the tendon to emerge proximal to the encircled strands of tendon on the opposite side Thus, when the suture is drawn toward the cut end of the tendon, it rides over the knot of the other suture as over a pulley and the longitudinal pull is converted to a transverse one

The process may be repeated on the other tendon end and the four sutures tied to bring the tendon ends together. Tack sutures are always placed through the edges of the apposed tendon to prevent displacement

Criss-cross stitch—This technic of joining tendon ends was popularized by Bunnell and also used by Garlock As originally described, a criss-cross

be abraded to make them adhere and a suture used to bury each end in the substance of the opposite tendon This method was first described by Leo Mayer and has been widely modified in making tendon transfers in general orthopedics I use this method with a slight modification, in which both tendon ends are buttonholed, when all the tendons are severed on the back of the hand

Protection of suture line—Wherever a tendon repair is made there is always some dense scar tissue that unites the tendon callus to the scar of the injury, thereby limiting function later Many failures from this cause can be prevented if the surgeon avoids this pitfall by arranging incisions and tissue closure so as to pedicle a little normal fascia or fat between the tendon repair and the adjacent laceration Thus, on the back of the hand a small flap of subcutaneous fat may be turned back to separate a tendon repair from a damaged underlying metacarpal On the front of a finger a flap of normal tendon sheath can be rotated about to separate the tendon repair from the skin laceration or placed between the tendons to separate the profundus from the sublimis, etc, as indicated The difficulty can also be avoided if the tendon juncture is moved slightly from the original laceration by cutting about ¼ in off one of the severed ends Thus the tendon juncture is advanced by removing tendon distal to the laceration and recessed by removing it proximally

CONTROL OF BLEEDING—After the tendons are repaired, the nerves should be sutured Bleeders are ligated with the finest possible material If the tourniquet is to be left on for more than an hour and a half, it must be released at this time and the tissues allowed to "breathe" for several minutes before it is reapplied After ligation of the major bleeding points gauze pressure will control bleeding The operation may often be carried out in two stages In the first, with the tourniquet applied, the wound is elongated and the tendons and nerves identified and tagged Then, with the tourniquet removed, the tendons and nerves are repaired and the wound closed

Drying of tissues should be avoided by occasionally flushing the wound with saline and by keeping the area away from the immediate field covered with moist sponges Modern surgical illumination is very intense, and considerable damage may be done if the tissues are allowed to become dry, especially if the tourniquet is in place Wound closure is preceded by a final flushing with saline

WOUND CLOSURE—The skin and subcutaneous tissue are closed with a single layer of sutures, leaving the deep fascia overlying the muscles and tendons open It is best to bring the corners or curves in the wound to-

is started about ¾ in back from the tendon end, one needle being passed straight through the tendon Then the needles are passed back and forth through the tendon three or four times, advancing each time, to emerge from the cut end The needles are then inserted in the other cut end of the tendon, passed back and forth for a similar distance and finally brought out fairly close together With traction made on the wires and countertraction on the distal tendon, the two tendon ends are slid together The wires are then knotted and cut short (Fig 87, *C*)

If the tendon ends are frayed or otherwise damaged by being pulled on with a hemostat, the damaged or crushed part should be cut off, preferably after the wires are inserted and just before the tendon ends are pulled together In doing this, one must avoid damaging the wires When silk or cotton sutures are used, it is customary to insert both needles at once as each stitch is made to avoid transfixing the suture material with a needle and thus complicating the sliding together of the tendon ends An approximation stitch may be necessary to obtain accurate apposition at the tendon juncture The more accurately the ends are joined, the better the results will be

When the pull-out wire is used, a criss-cross stitch is inserted in the proximal tendon end and both needles are passed straight through the distal tendon end and out to the skin in a direct line (Fig 87, *B*) The wires are then threaded through the holes of a small button, such as a shirt button Traction is made on the wires distally, pulling the proximal tendon end down, and countertraction is made on the distal segment with a fine pair of thumb forceps to bring the cut ends together The wires are then knotted over the button and an additional approximation stitch or two placed at the tendon juncture to align the ends properly

The pull-out wire is a slightly larger wire which is looped through the proximal end of the criss-cross stitch before the criss-cross is tightened Both ends of the pull-out wire are threaded on a needle and passed out through the skin at a point slightly proximal to the tendon juncture

Which method of tendon suture is superior in a given case depends more on the operator's familiarity with and ability to master the technic than on anatomy or function

Buttonhole technic—When extensor tendons are joined, the thin, flat character of the tendon on the back of the hand does not lend itself well to either of the foregoing suture methods Under some circumstances, it may be preferable to join the tendon ends by overlapping them slightly, drawing one tendon through a small incision made in the other (see p 186). When this is done, the adjacent surfaces of the tendon ends should

The pull-out wire, if used, is left for a similar period. At the end of this time the button on the end of the finger is cut off and the wire withdrawn by making steady traction on the pull out At this time the tendon juncture is still weak, but the wire is no longer necessary to hold it to-

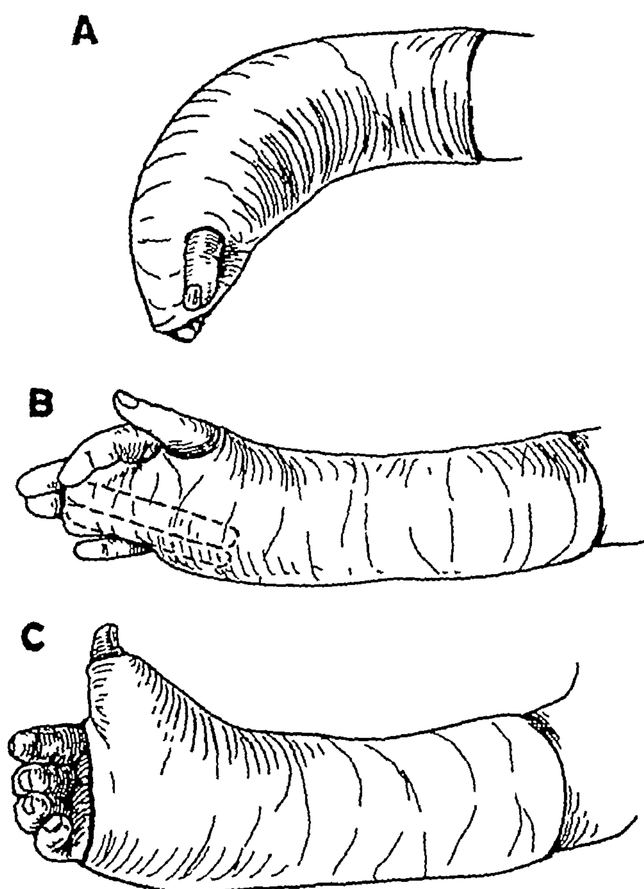


FIG 88—*A*, correct splinting for flexor tendon *B*, splinting for repair of extensor tendons of long and ring fingers *C*, splint for long extensor of thumb

gether. Guarded, active exercises are now instituted, the patient being instructed to exercise the finger as often as possible but to avoid exercise against resistance As further healing occurs, motion gradually increases during the next two weeks The patient is instructed to stabilize the proximal or middle joint, as the case may be, and to exercise the joints beyond it It is important during this period for the patient to exercise persistently and to try to pull the tendon through the sheath actively. Full flexion is always more important than full extension, and all postoperative exercises should aim at establishing this function Frequently, little motion is present at first, but with persistent exercise the range of motion will

gether first, using interrupted half-buried mattress sutures Then the repair is completed with interrupted vertical mattress sutures which penetrate all layers down to the deep fascia Any areas of skin of doubtful viability should be sutured with half-buried mattress sutures, the stitch being inserted and tied on the side which presents maximal viability Probably the only indication for use of a drain would be a continuous oozing of blood which cannot be controlled by pressure Appropriate dressing and splinting are very important

SPLINTING—The extremity should be carefully supported during wound closure and until splints can be applied A single layer of grease gauze is placed over the incision This is followed by dry gauze and suitable compressible material, such as Kerlix, compression cotton or mechanics waste During these steps the surgeon or his assistant should hold the extremity in a position which relaxes the tendons For extensor tendons, the wrist is extended and the fingers or thumb extended, depending on what has been repaired Plaster of paris splints are laid over the volar surface of the compressible material, the desired position of the extremity being maintained until they are practically dry For flexors, the plaster is placed on the dorsum, and the wrist should be in moderate acute flexion to take the pull off the tendons (Fig 88).

A thin layer of sheet wadding wrapped around the compressible material before the plaster of paris is applied facilitates removal of the splint Some surgeons use elastic bandages over the compressible material A little care is necessary if these are used because it is possible to get them too tight Joints should never be immobilized at their extremes By relaxing them just a little as the plaster dries the right position will be obtained Padding should be placed between the fingers, and the thumb should always be kept away from the palm

POSTOPERATIVE CARE—As soon as the patient is returned to bed, the hand is elevated as high as possible It is good practice always to give antibiotic therapy for two or three days postoperatively and it is well to add 250 mg of vitamin C three times a day to the diet The latter promotes rapid wound healing by its action on the fibrin content of the blood and aids in antibody formation

Although wounds in the palm of the hand or fingers do not heal substantially in less than 10 days, it is well to change the dressings at the end of the fourth or fifth day to assay the extent of healing and to cleanse the wounds If everything goes well, the patient may be discharged from the hospital in three to five days

The plaster cast is left on for three weeks in all *flexor* tendon injuries

The pull-out wire, if used, is left for a similar period At the end of this time the button on the end of the finger is cut off and the wire withdrawn by making steady traction on the pull out At this time the tendon juncture is still weak, but the wire is no longer necessary to hold it to-

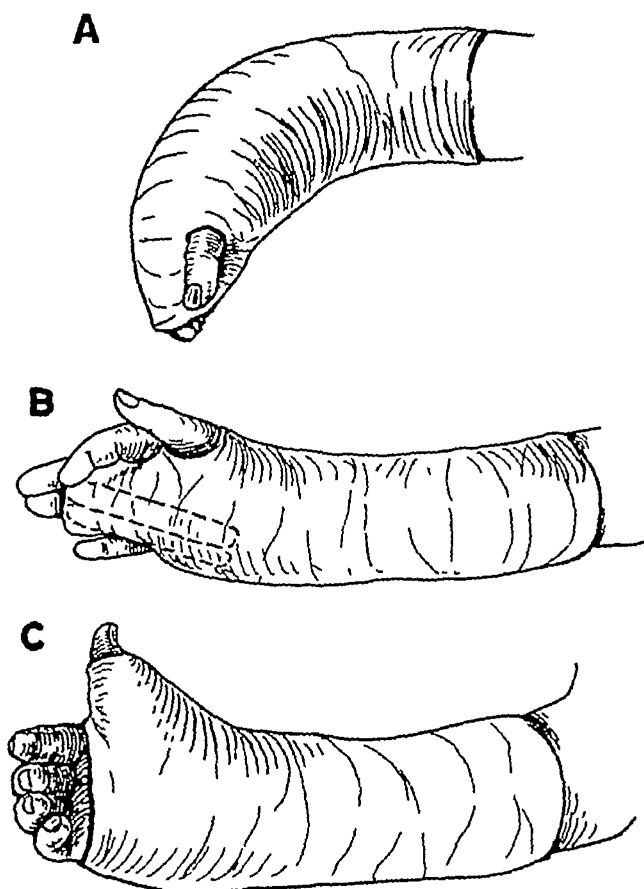


FIG 88—*A*, correct splinting for flexor tendon *B*, splinting for repair of extensor tendons of long and ring fingers *C*, splint for long extensor of thumb

gether Guarded, active exercises are now instituted, the patient being instructed to exercise the finger as often as possible but to avoid exercise against resistance As further healing occurs, motion gradually increases during the next two weeks The patient is instructed to stabilize the proximal or middle joint, as the case may be, and to exercise the joints beyond it It is important during this period for the patient to exercise persistently and to try to pull the tendon through the sheath actively. Full flexion is always more important than full extension, and all postoperative exercises should aim at establishing this function. Frequently, little motion is present at first, but with persistent exercise the range of motion will

gradually increase, and improvement can be expected up to 12 months in favorable cases In unsuccessful cases a little motion is present at first but stiffening gradually occurs until there is no motion at all in the interphalangeal joints, the finger moving actively only at the metacarpophalangeal joint If no motion has been present for several months, it is unlikely that any improvement will take place and the repair should be considered a failure Tendon grafting is then indicated (Chapter 13)

On the extensor side of the hand, skin incisions usually heal within a week and skin sutures may then be removed If pull-out wires have been used, they may be removed at the end of three weeks and guarded exercises instituted It is usually advisable to remove the splint during the day and to replace it at night for an additional two weeks since extensor tendons are often pulled apart by the patient in his sleep

Extensor Tendon Injuries

Anatomically the extensor tendons vary considerably from their musculotendinous origin in the forearm to their final insertion on the back of the digits On the dorsum of the lower forearm these tendons are rounded The finger and thumb extensors lie between the wrist extensors, the adductor and short extensor of the thumb along the side of the radius Beneath the dorsal carpal ligament are short tendon sheaths which complicate repairs unless steps are taken to prevent adhesions On the back of the hand the extensor tendons become flattened and require a different suture technic On the dorsum of the fingers the complicated extensor aponeurosis presents a problem entirely different from that in any other tendon area

The charts in Chapter 1 (Fig 1) show the anatomic relations of these tendons much more succinctly than they can be described The dorsal carpal ligament is actually only a thickening of the deep fascia Proximal to this area the deep fascia gradually thins out as it reaches from the tendinous to the muscular area, and distally over the back of the hand the fibrous elements are largely replaced by fat The extensor aponeurosis over the back of the fingers really consists of three separate tendons (see Fig 4), each with its own muscle, when only one of these is cut, the others will perform its function On the back of the hand the juncturae tendina may extend the middle, ring or little fingers even after their own extensor tendons are severed

The extensor mechanism on the back of the thumb is similar to that of the fingers, with the abductor and adductor pollicis muscles making

part of their insertion in the lateral edges of the main extensor tendon With only two phalanges to extend, the mechanism is much simpler than the finger extensor mechanism, there being an aponeurotic hood over the proximal joint and a flattened band extending down to the distal joint

To extend the fingers fully the extensors on the back of the hand must move about 1 in Over the back of the proximal phalanx this excursion is reduced to about ½ in, and over the middle phalanx to ¼ in Above the wrist an additional 1 in of excursion is necessary to make up for the various positions of the wrist The space between the extensor tendons and bones is occupied by a thin layer of areolar tissue which provides the tendons with an adequate sliding medium

ETIOLOGY—On the back of the forearm where the tendons are protected by the prominences of the radius and ulna they may be severed by deep puncture wounds Complicated wounds with loss of skin over the tendon and frequently an underlying fracture also sever tendons Under the dorsal carpal ligament or immediately proximal or distal to it, tendon ends often retract out of the other side of the ligament, making repair more difficult On the dorsum of the hand the extensor tendons are more exposed, and here any laceration or even a direct blow with a blunt instrument may sever them The extensor pollicis longus is particularly vulnerable in the snuffbox region

Because of the breadth of the dorsal aponeurosis over the proximal portion of the finger and the convexity of the dorsum of the finger, the extensor mechanism is seldom completely severed in this region by a simple laceration Usually the central band and a portion of one of the laterals are cut The entire aponeurosis may be severed by an avulsion caused by a ring which is caught while the person is going down a ladder or by a glove caught in a machine Sometimes it is also completely severed by a deep saw cut which partly transects the phalanx Over the middle phalanx a somewhat similar situation exists Usually one lateral band is severed or avulsed and the other band remains intact The vulnerable spots in the dorsal aponeurosis are over the middle and distal joints of the fingers Here the tendon is very thin and unprotected and is easily torn where all the fibers converge into a single insertion In these locations the tendon may be ruptured subcutaneously by a blow from a blunt instrument, it may be severed by a minor laceration or it may be torn apart by a violent strain

The simplified extensor mechanism of the thumb makes this tendon more vulnerable to lacerations over the dorsum of the proximal phalanx than the corresponding region in the finger It can easily be severed by

a knife cut or similar injury However, it is considerably stronger over the joints and is less liable to subcutaneous rupture or avulsion than is the finger extensor

DIAGNOSIS—The diagnosis of a severed extensor tendon is usually obvious, although sometimes there is little disability in the involved finger because of the action of the juncturae tendina The interossei and lumbricales act as extensors of the distal two joints and though the proximal joints assume a semiflexed position after the common extensor tendons of the fingers are severed, the distal two joints can still be fully extended by the intrinsic muscles (Fig 89) The findings are about the same whether the finger extensors are severed just back of the knuckles



FIG 89—Appearance of hand with severed extensor tendons of long and middle fingers Middle and distal joints of fingers extended by intrinsic muscles

or above the wrist, except that close to the fingers they are more pronounced If the dorsal aponeurosis is torn across, both joints distal to the injury will assume a flexed position When the central band is cut or ruptured over the middle joint, this joint becomes acutely flexed due to the unopposed action of the flexor tendons, but the distal joint remains extended due to the action of the intact lateral bands In old, neglected injuries of this type the lateral bands prolapse around the sides of the finger and act as flexors of the middle joint while the distal joint gradually becomes hyperextended as these bands remain in a constantly tensed state (Fig 90, *A*)

In the middle segment of the finger the extensor tendon divides into two slips which lie dorsolateral on the phalanx, hence it is uncommon for both to be completely severed Normal function is obtained if either side is intact

When the tendon is ruptured or cut near the insertion on the distal phalanx, this joint becomes acutely flexed, giving the so-called mallet finger deformity (Fig 90, *B*) In old cases, the lateral bands retract and

the central tendinous insertion into the middle phalanx gradually brings the middle joint into a hyperextended position

In the thumb, severance of the long extensor always results in the distal joint assuming a flexed position If the injury is in the snuffbox region, the short extensor may still extend the metacarpophalangeal joint Division of the short extensor alone gives rise to few symptoms Division of the abductor pollicis longus makes the thumb unstable on pinching and may produce considerable pain on abduction

The wrist extensors can have their functions taken over by the tendons of the digits In testing, the patient is asked to relax the fingers and thumb and then to extend the wrist toward both the radial and ulnar sides.

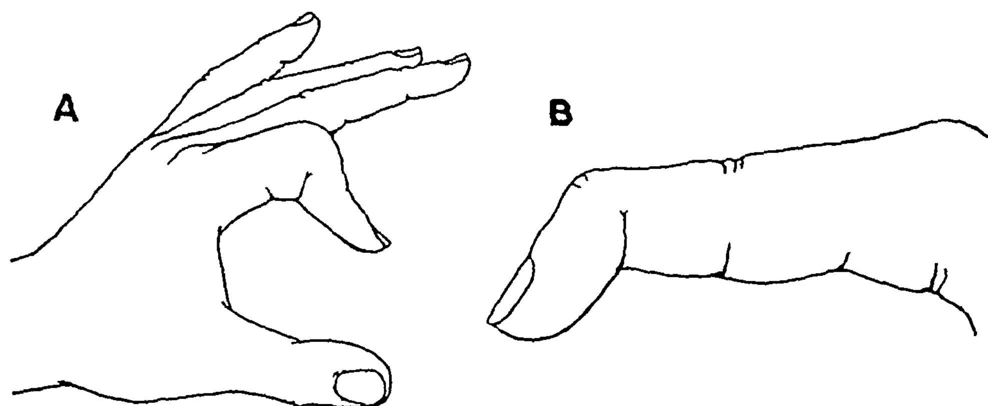


FIG 90—*A,* typical appearance of old case of rupture of insertion of central band of extensor tendon over proximal interphalangeal joint *B,* mallet-finger deformity

Whenever a tendon is cut or ruptured subcutaneously a comparison examination should be made of the uninjured hand One should also attempt to palpate for the tensed tendon If the extensor tendon has been severed and the skin wound heals without the tendon being repaired, the separated ends of the tendon can sometimes be palpated moving beneath the skin when the hand is opened and closed

TREATMENT—*Back of the forearm*—L- or Z-shaped incisions place intact skin over sliding tendons T-shaped, cross-bow or incisions which run directly across joints are never as good, and troublesome scars result because of adhesions Either end of the traumatic laceration may be extended by a blunt curve running up the border of the arm and a triangular skin flap turned up, giving excellent exposure. With a similar incision from the opposite end of the laceration down the other border of the forearm, a flap can be turned down distal to the laceration In a

bloodless field and with a little care the sensory branches of the radial and ulnar nerves are easily avoided

After the skin flaps are turned back, a linear incision is made through the deep fascia directly over the severed tendons Hyperextension of the fingers and wrist will bring the severed tendons distal to the laceration back into view Tendon identification and proper matching of ends are facilitated by keeping the tendons in their proper position There will then be no difficulty in matching of correct ends unless there has been considerable tendon destruction In this location, end-to-end suture by one of the methods previously illustrated should always give a good result.

Dorsal carpal ligament.—When tendons are severed close to this structure, certain precautions must be taken to avoid adhesions following repair If the *long extensor of the thumb* is severed in the anatomic snuff-box with the wrist and thumb flexed, the tendon juncture will lie in the ensheathed portion over the lower end of the radius when the hand is properly splinted in extension During healing the tendon juncture will be compressed in a bony trough with a dense ligament on top, it becomes adherent and will not loosen later Extending the thumb and the wrist will determine whether or not the tendon juncture will lie in this sheath during healing To prevent adhesions from checkreining the tendon later, the sheath in this region should be split around the tendon juncture and left open Since the pollicis longus requires more excursion than other extensor tendons, there is greater disability after its repair than after repair of any of the other extensors When this tendon is severed in its sheath, better results are often obtained if it is replaced later by a graft in an elective procedure

The *wrist extensors* as well as the long abductor or short extensor of the thumb can be repaired within their sheaths and the repair decompressed by splitting the sheath and leaving it open If the *extensor digiti quinti proprius* is cut and repair effected within its sheath, the same result may be expected as in the thumb Checkreining causes the metacarpophalangeal joint to be held straight, and such flexion as occurs will be in the distal two joints To avoid this, the tendon may be transferred into a good tendon in the common extensor group away from the dangerous area under the ligament, or the compartment for this tendon may be split

The *extensor indicis proprius* and the *extensor digitorum communis,* when sutured beneath the dorsal carpal ligament, give better results than the proper extensors of the thumb or little finger because the space they occupy is relatively larger and only one bony trough is present for all five tendons Simple decompression obtained by making an incision in the

dorsal carpal ligament will suffice, provided the tendon junctures heal properly

Dorsum of the hand—On the dorsum of the hand the extensor tendons of the digits are easy to repair, and either end-to-end tendon juncture or interweaving will give good results provided the digits and wrist are splinted in extension during healing and the original wound in the skin heals properly The tendon should not become sufficiently adherent to deep structures here to interfere with good function

When *many tendons are cut* on the back of the hand or wrist where the tendons are small and flat, a practical shortcut for tendon juncture is the buttonhole technic (Fig 91) In the method described by Mayer, a longitudinal slit approximately ⅛ in long is made ¼ in from the end of one tendon Through this slit the other tendon end is drawn by means of a mosquito clamp so as to overlap the first ½ in (Fig 91, *C, left*). A stitch is then taken directly through the commissure, transfixing both tendons, and the needle is reversed to take a second stitch in the opposite direction The suture is tied at once, with the knot placed to give least interference with the gliding motion of the tendon, this is usually on the lateral aspect of the tendon Two sutures are placed on either side of the first, these are transverse vertical mattress stitches which pass through tendon ends and fold recipient tendon about them The clamps are then removed and the traumatized tips of the tendons cut off obliquely to facilitate implanting these free ends in minute, longitudinal slits made in the tendons Those surfaces of the tendon which come in contact with one another should be scarified to encourage adhesion, and those portions which are to serve as gliding surfaces should be most carefully protected from trauma

I prefer a slight modification of this technic, in which both tendon ends are buttonholed and each free end is drawn through the hole in the other tendon end with a mosquito hemostat Two transverse wire mattress sutures are then used to fasten the tendons in the holes and draw tendon tissue around the tendon ends (Fig 91, *C, right*) These are tightly knotted and the mosquito hemostats removed Usually the tendon ends retract slightly and become neatly buried

This method is only applicable for tendons which move through loose connecting tissue and which can be overlapped It is not particularly valuable when only one tendon is cut but will give a good result when all the tendons are severed, because, although the tendons are slightly shortened, a minimum of suture material and of manipulation is necessary

In axe wounds, deep glass cuts and similar injuries on the dorsum of

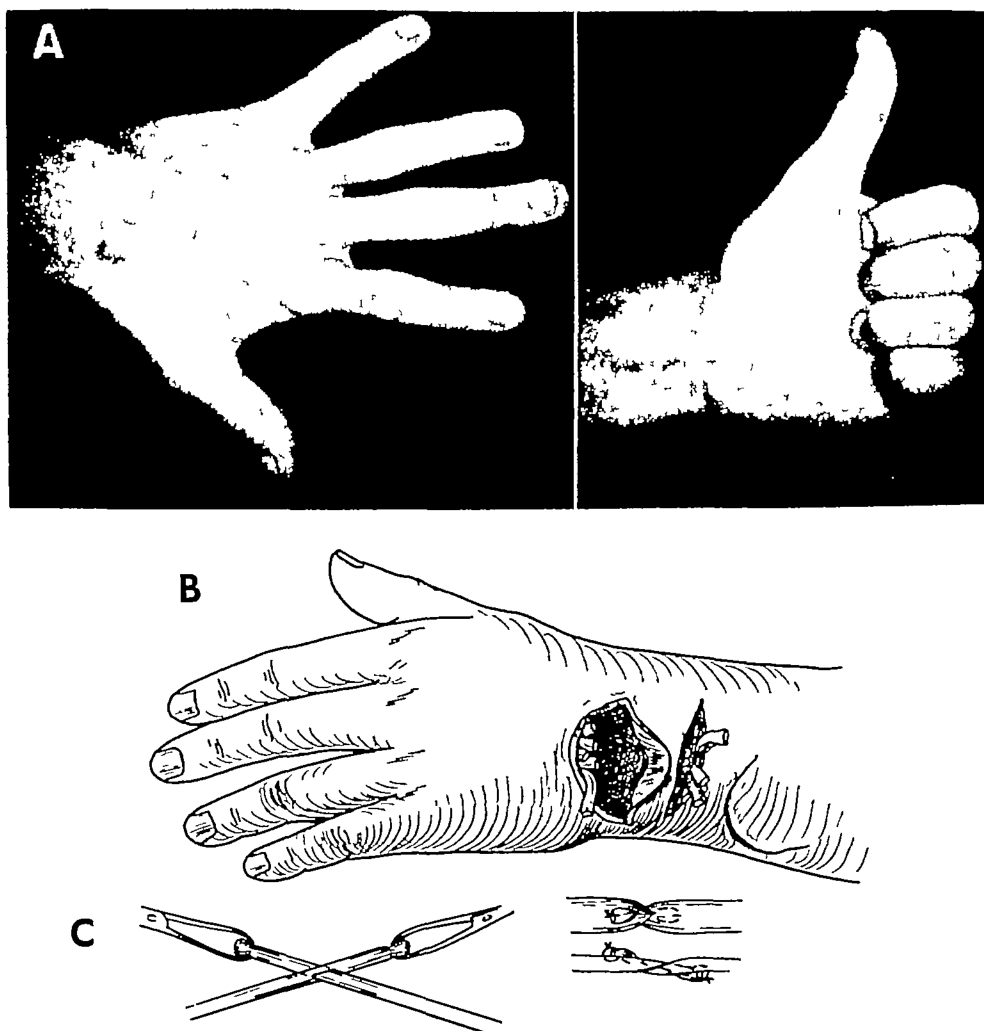


FIG 91 —Deep laceration across back of wrist severing all extensor tendons of fingers and the extensor carpi ulnaris *A*, full return of function 11 months later (from Nichols Northwest Med 48 327, 1949) *B*, diagram of injury Repair was by buttonhole method of joining tendon ends *C*, *left*, Mayer technic, *right*, both ends buttonholed Additional mattress sutures bury ends of tendon

the hand, a common complication is denudation and chip fractures of the metacarpals underlying the injured tendons In such wounds the tendon repair should be protected from binding adhesions by suturing a thin layer of fascia pedicled from the subcutaneous tissues beneath the repair

Dorsum of the finger—From the point where the extensor tendons insert into the dorsal aponeurosis just proximal to the metacarpophalangeal joints to the distal extremity of the extensor mechanism, the method

of healing and the problem of repair are quite different Over the dorsum of the metacarpophalangeal joint the tendon spreads out as a broad aponeurosis with a central thickening Directly beneath the tendon is the joint capsule which is often simultaneously injured Deep wounds in this region often cut clear through the aponeurosis and joint capsule, even severing nerves and tendons on the palmar surface of the hand When healing occurs there are bound to be some adhesions between the extensor aponeurosis and the joint capsule, resulting in stiffness of the finger

Proximal joint—In uncomplicated cases in which only the central expansion of the aponeurosis is severed, simple repair is adequate A mattress suture through the heavy part of the tendon or a removable wire suture through the skin and tendon will hold the tendon ends together if the finger and wrist are kept extended during the process of healing (Fig 92) The mattress suture is more easily tied if the knot lies distal to the juncture and the loop proximal, allowing the proximal tendon to be pulled down as the knot is tightened The small rent in the joint capsule is left alone

In more complicated cases the entire circumference of the joint capsule may be severed, as well as the entire extensor aponeurosis and possibly a portion of the bone end, and repair is much more difficult (Fig 93) The joint is usually subluxated and, if allowed to heal without suitable repair, will be drawn further out of place, upsetting the balance of the hand Normal relationships must be restored The metacarpophalangeal joints are the most important joints in the fingers and even a small range of motion is of great value

Since the supply of blood is carried on the volar surface of the finger, if tissue has not actually been lost a satisfactory primary repair can be made The sacrifice of any good-sized piece of bone around the joints should be avoided Usually either the phalanx or the metacarpal is cut but not both, so that one good part of the joint mechanism remains The loose piece of bone can generally be approximated to the adjacent phalanx or metacarpal by sutures inserted in the joint capsule or periosteum If part of the metacarpal head is detached, it can be pinned back in place with a small nail or brad The cancellous nature of this bone permits early healing The joint capsule must be resutured as accurately as possible with interrupted sutures of fine stainless steel wire The finger should be held in its correct position during suturing to avoid axial rotation

The entire extensor aponeurosis should then be repaired as accurately as possible, using interrupted mattress sutures to evert the edges and prevent the tendon from becoming adherent to the underlying joint cap-

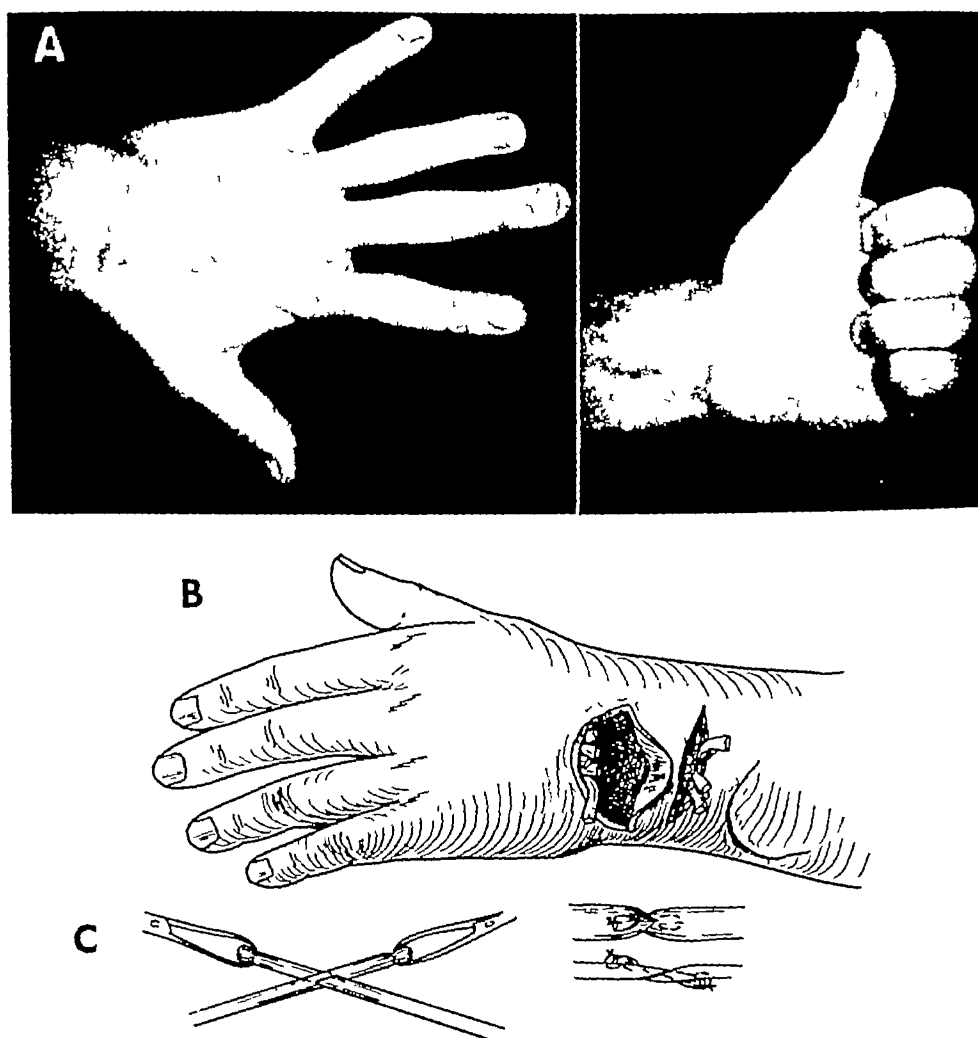


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Dorsum of the finger—From the point where the extensor tendons insert into the dorsal aponeurosis just proximal to the metacarpophalangeal joints to the distal extremity of the extensor mechanism, the method

by x-rays After two or three weeks of immobilization active exercises are begun, but no strain should be put on the healed area

Proximal phalanx—The aponeurosis is rarely completely severed *When a tendon is incompletely severed, the least that is done to repair it the better* If the central, thickened portion is cut, it is usually advisable to insert a single suture here to prevent the aponeurosis from tearing further Proper splinting will take the tension off the suture line and

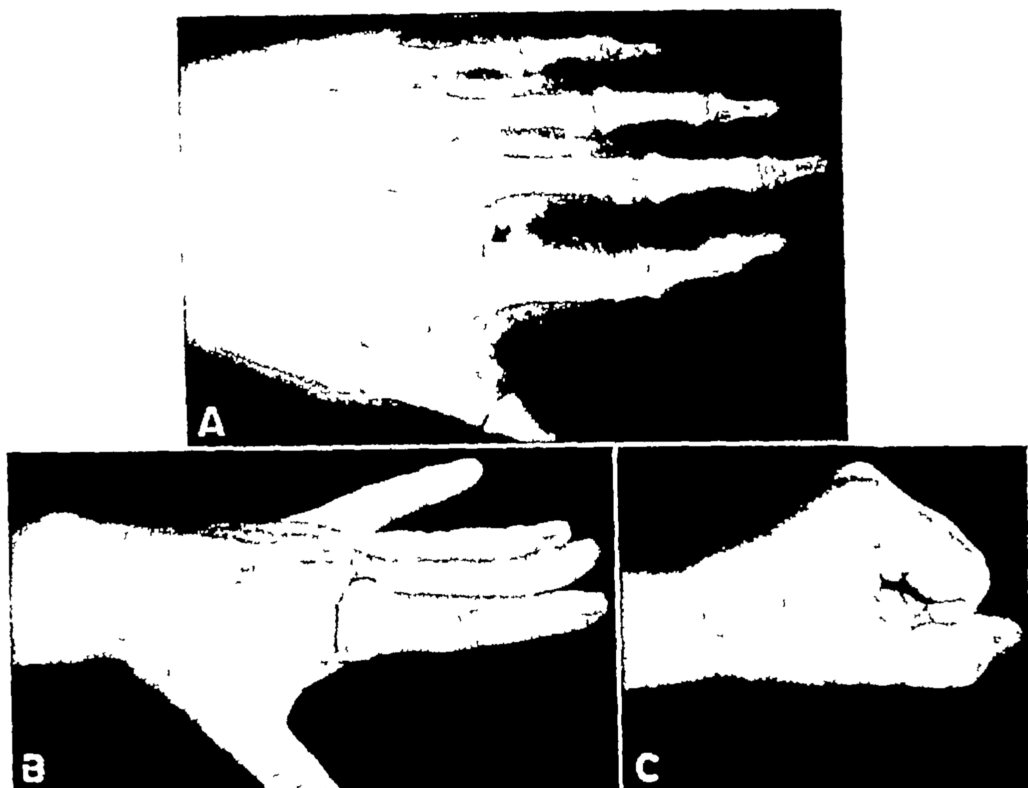


FIG 93—*A*, axe wound through index metacarpophalangeal joint, severing extensor, joint capsule and bone Volar digital nerves and profundus tendon were partially severed *B* and *C*, function one year after primary repair (scar retouched in *B*)

allow perfect healing, provided the overlying skin is not lost or the underlying bone damaged If the skin is lost but the tendon is not too severely damaged, the wound is debrided and covered with a free split thickness skin graft In those instances in which the tendon is completely torn through, such as in a ring avulsion, considerable stiffness will invariably result To repair the tendon and resurface the dorsum of the finger without losing the sliding mechanism of the extensor aponeurosis is difficult So much scarring is present, frequently with loss of circulation, that stiffness is inevitable

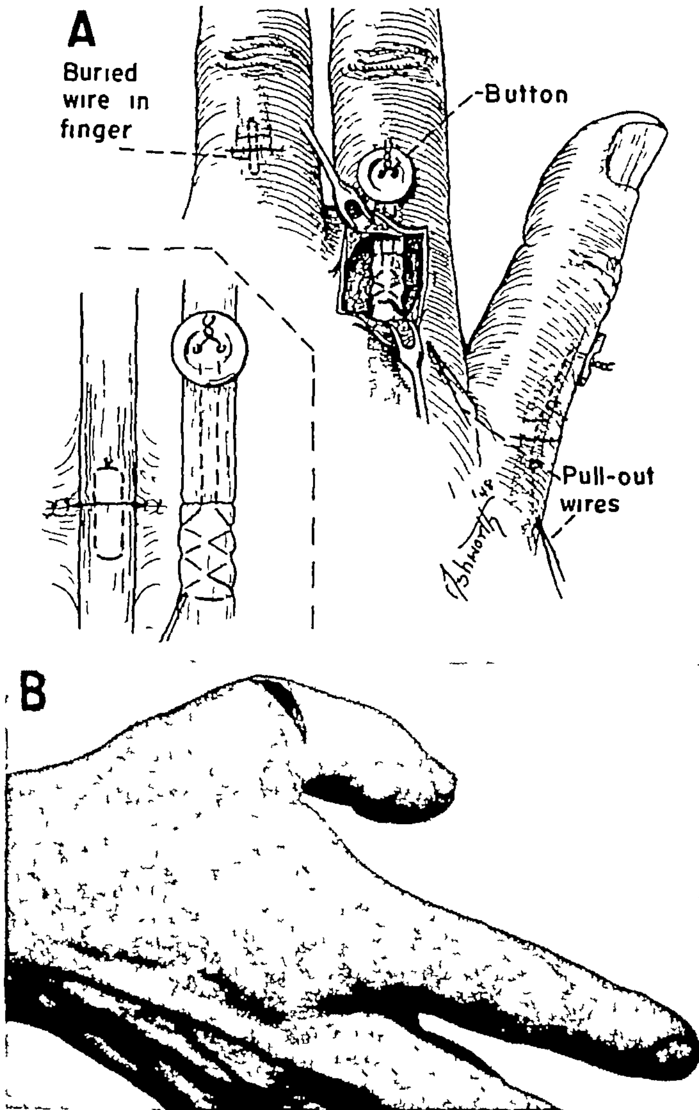


FIG 92—*A*, methods of repair of extensor tendons over metacarpals or proximal phalanges simple mattress suture which is left in, or removable wire which is later withdrawn. *B*, typical injury in which thumb extensors are cut

sule as much as possible A heavier stitch is taken through the central, thickened, tendinous portion The joint should flex fairly freely if the repair is properly done The aponeurotic tendon of the interosseous muscle as it turns around the lateral sides of the joint must also be repaired The fine tendon of the lumbrical muscle is usually not suitable for repair but not much disability results if it is ignored During healing the wound should be closely watched and the condition of the severed bone followed

A similar difficulty is encountered when the tendon and phalanx have been severed by a saw Repair of the extensor tendon along with the bone may be carried out in this situation, with the expectation that the fracture site and tendon juncture will become adherent A secondary procedure will then be necessary to free the extensor tendon If the flexor tendon is severed at the same time, it should never be repaired primarily At a later date when a graft is used to replace the flexor tendon, the extensor tendon is freed and some sliding material inserted to prevent readherence

Middle joint—Over the dorsum of the middle joint the extensor mechanism is particularly vulnerable to injury The central slip of the aponeurosis is quite thin as it passes over the center of this joint, and its insertion into the dorsal lip of the proximal articulating surface of the middle phalanx is relatively small and weak (see Fig 4) After this portion of the tendon is severed or ruptured, the two lateral bands which extend the distal joint slide volarward around the middle joint and tend to flex rather than to extend this joint This injury is often overlooked, and in a week or two the middle joint of the finger assumes a flexed position Then, voluntary extension only results in extension of the distal joint, the middle joint being further flexed by the split extensor mechanism (see Fig 90, *A*)

For this injury neither primary repair nor secondary reconstructive procedures as customarily described are completely successful in restoring function Frequently, the central tendon slip is actually avulsed from the bone To anchor the tendon back in place, a small hole may be drilled through the dorsal articulating lip of the phalanx and a wire passed through the hole (Fig 94) The wire ends are mattressed through the tendon If the central portion of the aponeurosis is torn as it passes over the joint, the torn ends of the tendon are often so fragile that primary suture will not hold Such fingers should always be splinted in extension to prevent the buttonhole deformity A satisfactory treatment is to restore the normal anatomy of the extensor mechanism later by using a small graft to replace the missing central tendon (see Chapter 13).

Middle phalanx—Distal to the middle joint the extensor mechanism is duplicated, there being two bands which are continuations of the lateral edge of the aponeurosis over the proximal phalanx These bands gradu-

← FIG 94—*A*, multiple saw cuts of all fingers, removing dorsum of middle phalanx of ring finger including insertion of extensor tendon and cutting slot in distal articular surface of proximal phalanx *B*, diagram of injury and primary repair, wire is passed through tendon end and drill hole in middle phalanx to fasten extensor tendon back into place *C* and *D*, almost normal function three months later

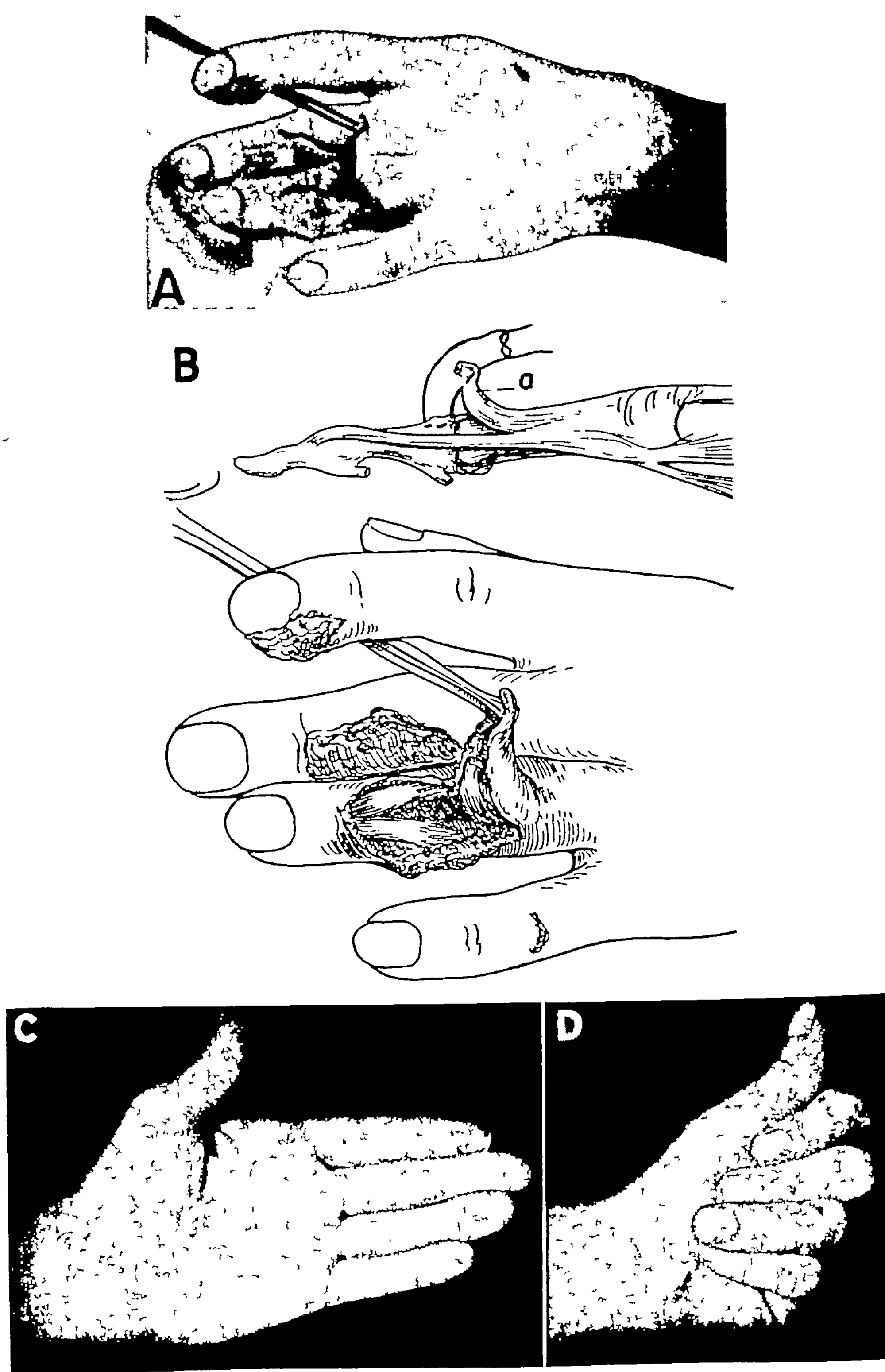


FIG 94

ally converge, to be inserted into the dorsal articulating lip and adjacent dorsal bony area of the distal phalanx If one lateral band is severed but the other remains intact there will be no loss of function unless scarring binds the tendon during healing Primary healing of the skin covering the tendon should be obtained, with as little done to the tendon as is compatible with satisfactory treatment of the wound Skin that is cleanly incised requires only simple suturing with splinting for one week, the severed tendon being ignored If the skin is partly torn away and one of the lateral bands is avulsed, lying partly attached in the wound, this portion of the tendon should be excised and the edges beveled The other lateral band will extend the end joint of the finger perfectly.

Both lateral bands are occasionally torn or severed Then, a simple mattress suture in each of the bands will be adequate to hold them during healing The finger may be splinted with the middle joint flexed and the end joint extended with a cast as in mallet-finger deformities Mason uses a cast which holds the wrist in about 45 degree extension, the distal joint of the finger in extension and the proximal and middle joints in slight flexion The wrist component of this cast is removed after about 10 days

Distal joint (mallet finger)—The thin extensor tendon over the distal interphalangeal joint is often injured Slight lacerations here frequently sever the tendon completely A subcutaneous rupture may be caused by a blunt object falling across the joint, or an avulsion may follow muscular violence The unopposed flexor tendon draws the distal phalanx into a flexed position and, after healing, the gap in the extensor aponeurosis is filled in by scar tissue, resulting in varying degrees of loss of ability to extend the distal joint When this condition has been present for some time, the constant effort to extend the distal joint, with all the extensor force being applied to the middle band which extends the middle joint, gradually draws the middle joint into a hyperextended position After this joint becomes permanently hyperextended the hand actually regains some function because the tip of the injured finger then lies approximately parallel with the other finger tips

A baseball finger is also produced when the dorsal articulating lip of the distal phalanx is fractured This detaches the bony insertion of the tendon, resulting in loss of voluntary extension The injury is often caused by a hyperextension of the distal joint, as in catching a baseball on the finger tip, the accident from which the condition derives its name Since

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of thumb, *E*, transfixion pin used for mallet finger repair, with this method middle joint is held flexed with collodion, *F*, Pratt's method of transfixion, with pin inserted to hold middle joint flexed

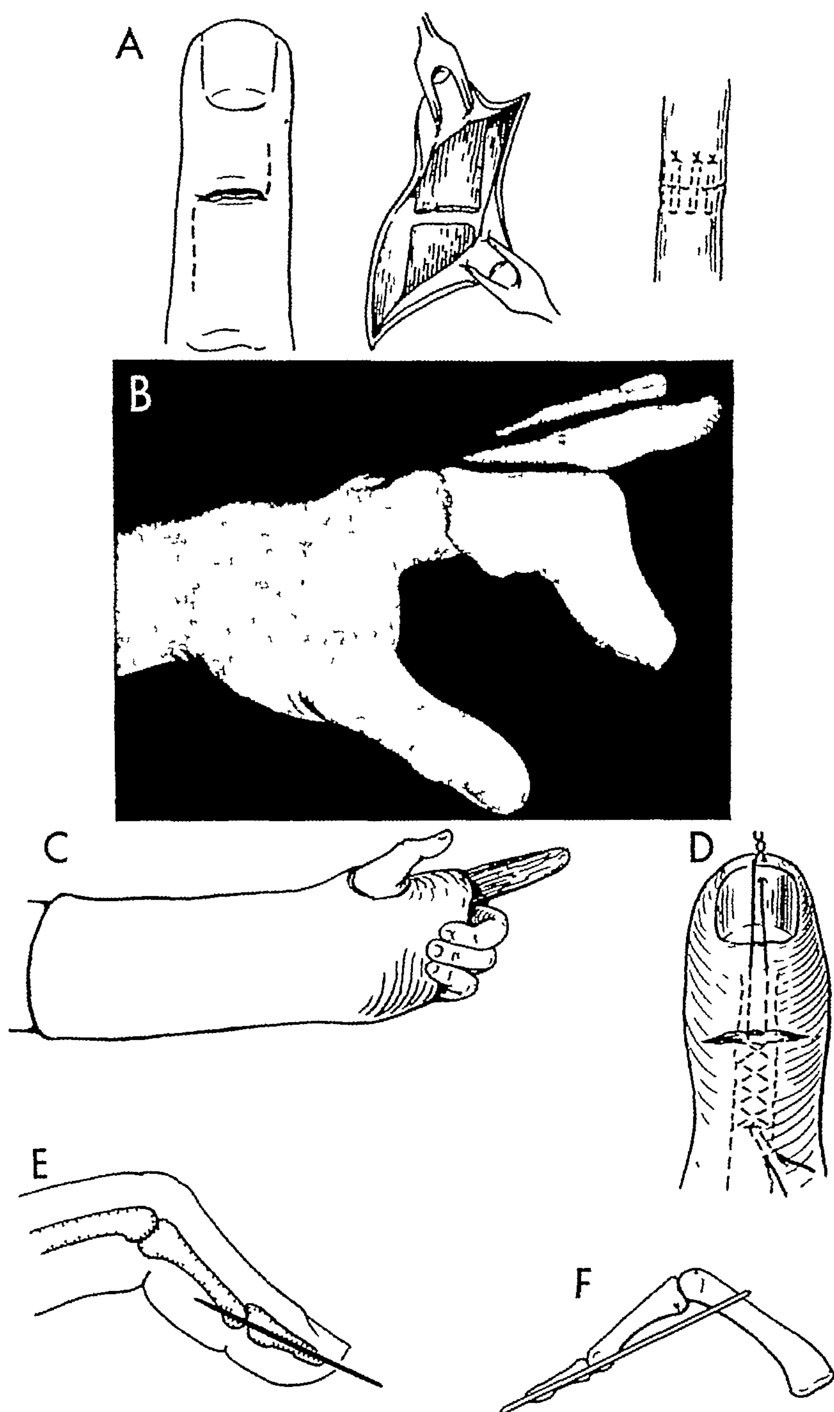


FIG 95 —*A*, technic of repairing extensor tendon cut over distal joint, in the thicker thumb tendon a pull-out wire anchored to the distal edge of the nail may be used (*D*), *B*, cast used in fresh mallet finger injuries (Bunnell method), *C*, splinting extensor tendon cut over distal joint, *D*, pull-out wire technic for repair of laceration of long extensor

ally converge, to be inserted into the dorsal articulating lip and adjacent dorsal bony area of the distal phalanx If one lateral band is severed but the other remains intact there will be no loss of function unless scarring binds the tendon during healing Primary healing of the skin covering the tendon should be obtained, with as little done to the tendon as is compatible with satisfactory treatment of the wound. Skin that is cleanly incised requires only simple suturing with splinting for one week, the severed tendon being ignored If the skin is partly torn away and one of the lateral bands is avulsed, lying partly attached in the wound, this portion of the tendon should be excised and the edges beveled The other lateral band will extend the end joint of the finger perfectly

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of thumb, *E*, transfixion pin used for mallet finger repair, with this method middle joint is held flexed with collodion, *F*, Pratt's method of transfixion, with pin inserted to hold middle joint flexed

the outward appearance is the same as that of a severed tendon, mallet fingers should be routinely x-rayed

Opinions vary considerably as to the correct treatment of fresh mallet-finger injuries, and results are apt to be disappointing My present opinion is that in fresh, cleanly *incised* wounds the best results will be obtained if the following technic is minutely carried out Skin flaps are turned up to adequately expose the tendon ends (Fig 95, *A*) and repair is carried out with interrupted mattress sutures of 6-0 silk or a fine pull-out wire anchored to the nail The skin is then closed and the finger splinted Either a plaster cast or a transfixion pin (Fig 95, *E* and *F*) to hold the finger in the position shown in Figure 95, *B*, can be used Another method of splinting is to apply a cast to hold the wrist in 45 degree extension and the finger straight, with the end joint hyperextended (Fig 95, *C*)

Mallet-finger injury in the thumb due to laceration of the extensor tendon over the distal joint is easily managed Here the tendon is comparatively thick, and repair by suture with a pull-out wire (Fig 95, *D*) will give a high percentage of good results The distal anchor wire is passed through the nail

Conservative treatment is recommended for *rupture* of the tendon if the injury is fresh Suture of a ruptured tendon over the distal joint is usually unsuccessful because the aponeurosis is extremely tenuous here and the sutures almost always tear out Some function can be restored by splinting Bunnell thought the middle joint should be flexed and the distal joint extended Flexing of the middle joint draws the central slip of the extensor mechanism distally, bringing the lateral bands with it, extending the end joint then brings the aponeurosis together The patient holds the finger in this position, pushing up on the tip with his thumb while the middle joint is voluntarily flexed, and a small plaster cast is applied without padding (Fig 95, *B*) Regular plaster splints cut into strips about 1 in wide and 3 or 4 in long are laid wet on the finger The patient holds the finger for a few minutes until the plaster is dry, and a little extra plaster is then applied over the tip Too much pressure over the back of the joint may cause a slough and should be avoided To keep the splint from coming loose an extension of the cast around the distal palm is useful If the injury is the fracture type, recheck x-rays should be taken after the cast is applied The cast is left on about a month and then removed and active exercises instituted The plaster cast is easier to apply and holds better than the metal splint which has been devised for this condition Donald R Pratt of San Francisco uses a transfixion pin to hold the finger in the correct position (Fig 95, *F*)

The cast treatment for fresh mallet fingers will not succeed in patients who carry on heavy muscular work during healing. Inevitably the cast will loosen and the deformity will actually become worse. These patients are difficult to manage, as it is hard to persuade them to accept treatment. Furlong of England remarks that patients co-operate better after surgical repair but that the most important element in treatment is time. In any case, the function of the finger should be carefully assessed. Fingers in which function is only partly lost should be splinted very conservatively. Extremes of splinting may actually make the condition worse.

Since in old cases there is actually a gap between the tendon ends which

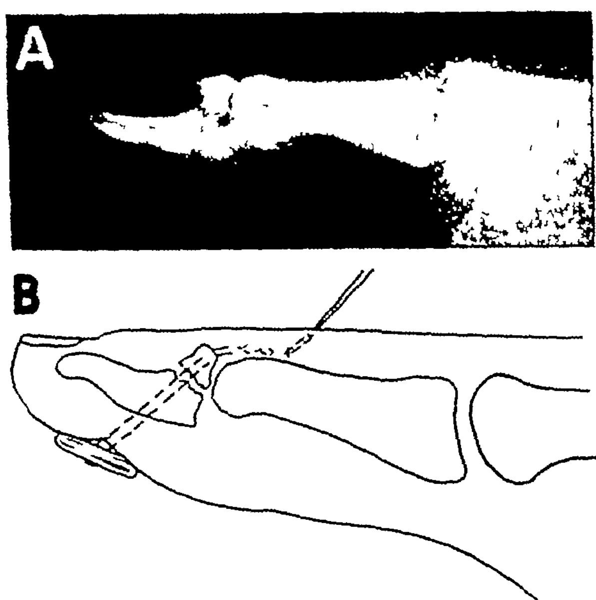


FIG. 96.—*A*, two week old mallet-finger deformity of thumb due to irreducible fracture. *B*, diagram of repair, a suture with pull-out wire is illustrated.

is filled in with scar tissue, splinting alone cannot be expected to be corrective. It is even more unlikely to be successful in old fractures because the bone fragments are actually held apart by scar. When fracture is not involved, the defect in the tendon can be corrected by a tendon graft operation (Chapter 13).

When a small fragment of the dorsal articulating lip of the phalanx is fractured off, healing can be obtained in fresh cases by splinting. If the fragment is large, subluxation of the joint will result and function will be seriously impaired. This condition should be corrected surgically. The fracture site is exposed through an incision which curves across the back of the joint and turns up the dorsolateral aspect of the adjacent phalanx.

The displaced bone fragment is dissected out, preserving the attachment of the extensor tendon, and a small hole is drilled diagonally through the main part of the distal phalanx A loop of wire is passed around the loose fragment of bone and through the extensor tendon and both ends of the wire then passed through the drill hole in the phalanx and out through the finger pad (Fig 96) Here they are tied over a button The skin is closed and the finger splinted with a transfixion pin or the mallet-finger plaster cast, using sufficient padding to prevent pressure necrosis At the end of three weeks the cast is removed and gentle active motion of the joint permitted One week later one of the wires tied over the button is severed, the button removed and the wire withdrawn

Spontaneous healing of extensor tendons is said to occur if the tendon ends are prevented from retracting by proper splinting This is more apt to be the case where the tendon is severed near a digital joint and less likely over the back of the hand, wrist or forearm. When the patient presents himself with a laceration which is too old to justify surgery, splinting should always be used and if this is not satisfactory the tendon repair can be done later

FLEXOR TENDON INJURIES

The volar surface of the extremity is divided into four main regions forearm, carpal canal, palm and digits Anatomically, the structure of the flexor tendons is much the same from the musculotendinous origin in the lower forearm all the way to the insertions The presence of tendon sheaths in the carpus and digits complicates the indications and technic for repairs in these regions

The anatomic charts (Fig 2 in Chapter 1) show the normal relations of the nerves and tendons There are three layers of tendons on the volar surface of the wrist. Two important nerves, the median and ulnar, accompany these tendons and are often confused with them after forearm lacerations, with disastrous results In the carpal region, the median nerve runs through the carpal tunnel with the flexor tendons of the digits while the ulnar nerve runs between the layers of the carpal ligament In the palm, each pair of tendons is separated by the lumbrical muscles and the digital artery and nerve The digital sheaths extend as far proximally as the metacarpophalangeal joints or distal flexion creases of the palm The bifurcation of the sublimis tendons occurs well proximal to the proximal interphalangeal joints so that over each of these joints there are actually three flexor tendons running within a common tendon sheath

The thumb tendon is covered throughout most of its course by the thenar muscles The innervation of these muscles from the motor branch of the median nerve is often damaged

ETIOLOGY—A great variety of injuries cause wounds on the volar surface of the forearm Falling through a window, falls onto sharp objects, injuries while swimming, catching the arm on projections while falling, machine tool accidents and suicidal lacerations are common examples The palm of the hand, being heavily protected, is used to protect the rest of the body from blows or falls Any sharp object which penetrates the tough overlying skin and fascia is apt to cut some important structure beneath Typical examples are: falling with a glass in the hand, breaking the porcelain handle of a faucet, grabbing a sharp knife blade or being caught by a sharp machine tool Such injuries sever nerves and tendons in the palm or digits In the digits an apparently trivial laceration may easily sever the tendons when they are tensed opposite the flexion creases where no subcutaneous padding is present The long flexor of the thumb may be severed by puncture wounds in the thenar region.

DIAGNOSIS—Diagnosis of a severed tendon usually presents little difficulty if a few simple tests are carried out The wrist flexors should be tested by palpating for the voluntarily tensed tendon Inability to flex the distal phalanx against resistance indicates that the *profundus tendon* is severed Although the patient may still be able to flex the middle joint with the sublimis tendon and touch the palm with the finger tip, the end joint will remain straight This situation usually occurs when the middle segment of the finger is lacerated but may also follow oblique puncture wounds of the proximal segment, the palm or the wrist

Injuries to the *sublimis tendon,* whether in the finger, palm or wrist, result in inability to clench the fist The finger tips may be brought back to touch the base of the palm by the intact profundus tendon, but the hand is closed loosely and the finger tips cannot usually be brought against the distal palmar crease To test the sublimis tendon of one finger the examiner holds the other fingers out straight and requests the patient to flex the injured one Normally, full active flexion at the middle joint should occur

When *both flexor tendons* of a finger are cut, as commonly happens in wounds of the proximal segment of the finger or of the palm, the finger can still be flexed at the metacarpophalangeal joint by the interosseous muscles, but the distal two joints remain straight The finger tip cannot touch the palm and the grasp is lost

Occasionally some confusing factors may be present In finger and palm

wounds the lumbricales and relaxing extensor tendons may feebly flex the distal segments of the fingers even though both flexor tendons are severed This motion is very weak The sensory and motor components of the median and ulnar nerve should always be tested Whenever doubt exists, a careful exploration of the wound is warranted

When the *long flexor of the thumb* is cut, the patient cannot flex the distal joint of the thumb although the metacarpophalangeal joint may still be powerfully flexed by the short flexors Some patients have a remarkably wide range of motion of this joint, obscuring diagnosis

TREATMENT —*Front of forearm and wrist proximal to carpal canal*— If no contraindications exist, primary repair in the lower forearm usually gives results which are superior to those of secondary repairs If any of the previously described contraindications to tendon repair (p 171) exist, primary repair will not be successful The anatomic complexity of the region makes repair of any severe injury a formidable procedure However, the tendons here have an ample blood supply and are surrounded by loose fatty tissue which allows for sliding, so that with successful repair good function should be restored

The skin incision should be placed so that it will not bind the tendons later It should always be made zigzag, from the ends of the laceration up and down the radial and ulnar borders of the arm The deep fascia should routinely be slit and left open to decompress the repair

Technically the procedure is easier if all structures are identified and tagged before the repair is begun Matching of tendon ends is aided by a thorough knowledge of anatomy and by pulling on the digital tendon ends to see which joints they move A core type of buried suture is probably best in the flexors of the digits For flexors of the wrist which are severed close to their insertions the pull-out procedure is suitable, with the wires fastened over buttons in the base of the palm

Repair of the damaged nerves is preferably done at the time tendon repair is carried out If tendons but not nerves are repaired, approximately one month of splinting is required before nerve repair is undertaken, and an additional month of splinting must follow *Excessive stiffening results* If the surgeon feels that the setup or armamentarium is inadequate for successful primary repair of both tendons and nerves, he should not do a halfway job The wound should be washed out and debrided, the skin closed, antibiotics given and the patient transferred to a suitable center where repair can be carried out If not within the safe time limit, repair can be carried out as a secondary procedure at the end of 30 days Meanwhile the small joints in the hand can be kept loosened by means of

physical therapy Secondary repair should not be used routinely because tendon proliferates, scarring occurs and more adhesions take place postoperatively

The results obtained in this region depend on the number of structures injured and the thoroughness of repair After any wrist injury, the uninjured tendons carry the injured tendons along with them, thus, good function is restored whenever the profundus tendons remain undamaged Even if most of the tendons and nerves on the front of the wrist are severed, a properly done repair should restore full function to the hand (Fig 97) Opinions differ as to whether the sublimis tendons should be



FIG 97 —Result three months after primary repair of deep transverse laceration of wrist which severed both sublimis and profundus tendons of middle, ring and little fingers, the ulnar nerve and flexor carpi ulnaris (From Nichols Northwest Med 48 327, 1949) For diagram of exposure used, see Figure 115

repaired routinely in this region Unless some complication exists I usually perform a complete repair

Carpal Canal—This region includes the *base of the hand* extending from the crease of the wrist to the cleft of the thumb, the region of the thenar eminence Deep wounds in this area are notoriously difficult to repair and crippling in their effects The nine flexor tendons of the digits and the median nerve are packed together in the carpal canal, and the ulnar nerve lies just adjacent in the superficial layer of the carpal ligament on its ulnar side

In the surgical approach, the sensory and motor branches of the median nerve on the radial side must be avoided, as well as the sensory and motor branches of the ulnar nerve on the other side A midline incision through the carpal ligament is not desirable It usually results in a certain amount of bow-stringing of the tendons and, in addition, places the scar in a most unfavorable position The proper approach is through a skin inci-

sion along the thenar crease, lifting up flaps of skin, dissecting out the ulnar nerve so that it will not be damaged and detaching the carpal ligament from the pisiform and hamate bones This incision can be continued up the forearm as a serpentine after making a transverse jog at the wrist When this wound is closed the skin incision and the incision in the transverse carpal ligament are offset from each other so that the tendons are protected during healing (Figs 98 and 114, *C*) Tendon repairs here are defeated because tendons are caught in a dense bony

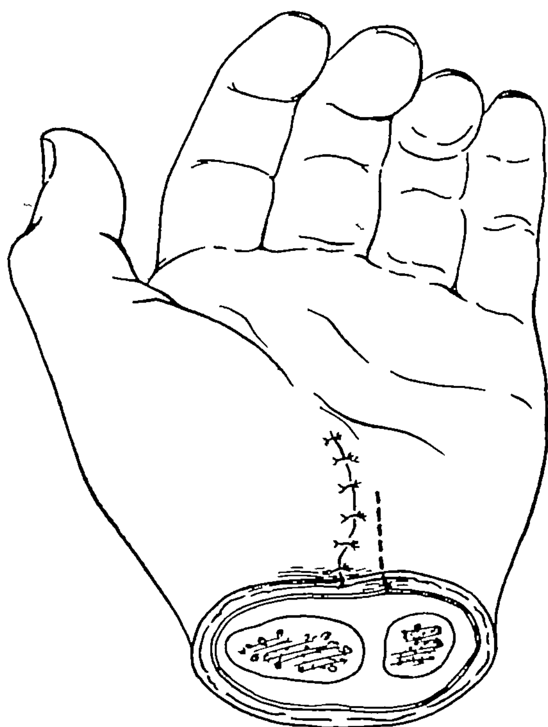


FIG 98—Offset incisions used to open carpal tunnel, dotted line indicates incision in transverse carpal ligament

canal when they heal and almost certainly will become adherent Some limitation of excursion therefore is inevitable after repair in this region (Fig 99) It may be much simpler to allow primary healing and later to thread a tendon graft through the intact carpal canal than laboriously to open the carpal canal and carry out a complicated and often worthless repair

Although opinions differ as to the exact course to follow in this region, the results obtained by primary repair are, in the aggregate, far from satisfactory and surgical intervention is not recommended unless carried out by expert operators under ideal conditions

Deep wounds of the *thenar eminence* present a complicated problem because the important motor branch of the median nerve is often severed Also, the flexor tendon of the thumb retracts farther than any other tendon and, covered as it is by the thenar muscles and their motor nerves, is most difficult to approach and repair The medial part of this region is actually a division of the carpal region and is best approached and treated in the same manner as a carpal canal injury The distal part of the thenar eminence is adequately exposed by a midlateral incision on the radial side of the thumb that extends from the base of the thumb metacarpal almost to the interphalangeal joint The thenar skin and subcutaneous tissue is turned up as a flap based medialward This incision

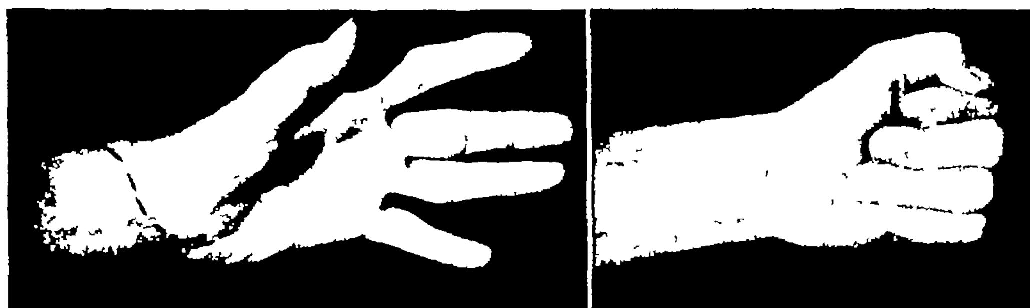


FIG 99—Function after repair of carpal canal injury Propeller of motorboat chopped up hand and forearm, sectioning flexor carpi radialis and palmaris longus in several places in forearm and severing tendons of thumb and index finger in carpal tunnel, second metacarpal was severed and greater multangular fractured Skin only was closed originally, one month later tendons were repaired, using graft for wrist flexor, and fractured metacarpal was wired together Dotted line shows location of incision used to approach carpal tunnel

gives nice exposure of the distal short thumb muscles, so that the flexor pollicis longus can be retrieved from between them or a branch of the median sensory nerves to the thumb can be repaired in this region (Fig 114, *B*)

PALM

MIDDLE OF THE PALM

The area lying distal to the thumb cleft and proximal to the distal flexion crease of the palm is a much more favorable area for repair The tendons for each digit lie in loose fatty tissue, and there is a fair amount of space between each pair The lumbrical muscles partially fill this space and provide an additional loose structure to protect the repair The multiplicity of structures, including tendons, nerves and muscles, which may be simultaneously severed and the proper anatomic exposure and recovery of the retracted tendon ends constitute the main problems If repair is

properly carried out, however, an early return to normal function may be expected (Fig 100)

Avulsion injuries of the palm are rare and the palmar fascia is practically never torn away Crushing injuries do not usually sever tendons even though the bones are comminuted, thus, even if the tendons are exposed by such an injury they will live if they can be covered and the viability of the flaps insured It develops therefore that, other than the location of the wound, the two most important factors are contamination and the operator's skill A faulty repair may be followed by scarring so severe that further attempts at repair are almost hopeless

The surgical incision should elongate the original palmar wound by following the creases in the palm Incisions which divide important structures or which will not heal well should be avoided In wounds over the thenar region or over the index and middle metacarpals, the logical approach is along the middle palmar crease or the crease at the base of the thenar eminence Such an incision can be prolonged proximally to the distal border of the transverse carpal ligament, with care taken to guard the median nerve motor branch Distally it can be turned up the radial side of the index finger, if this finger is involved, or toward the cleft between the index and middle fingers if the middle finger is involved The surgical incision should extend from the ends of the laceration

When the wound is over the ulnar side of the hand a suitable approach may be made by an incision along one of the palmar creases which is turned down toward the base of the palm along the line between the fourth and fifth metacarpals Occasionally a long transverse laceration extends across the palm at right angles to the palmar creases, on a line between the base of the little finger and thumb To extend such an incision requires a T-shaped extension running along one of the palmar creases (Fig 100, *B*)

The damaged tendons and nerves should then be identified A careful preoperative examination makes this maneuver simpler The digital nerves are often picked up with the vessels which lie adjacent to them The skin edges must be lifted up along with the palmar fascia, by retraction of these layers and dissection beneath, the nerves can be identified Once the end of the nerve is exposed, it can be picked up and mobilized by a little gentle traction with flexion of the digit or the wrist The nerve repair should not be done until the tendons are identified and sutured

The distal ends of the tendons are easily exposed by flexing the finger to make the ends of the tendons appear in the wound The proximal ends are recovered by retracting the skin edges near the distal edge of the

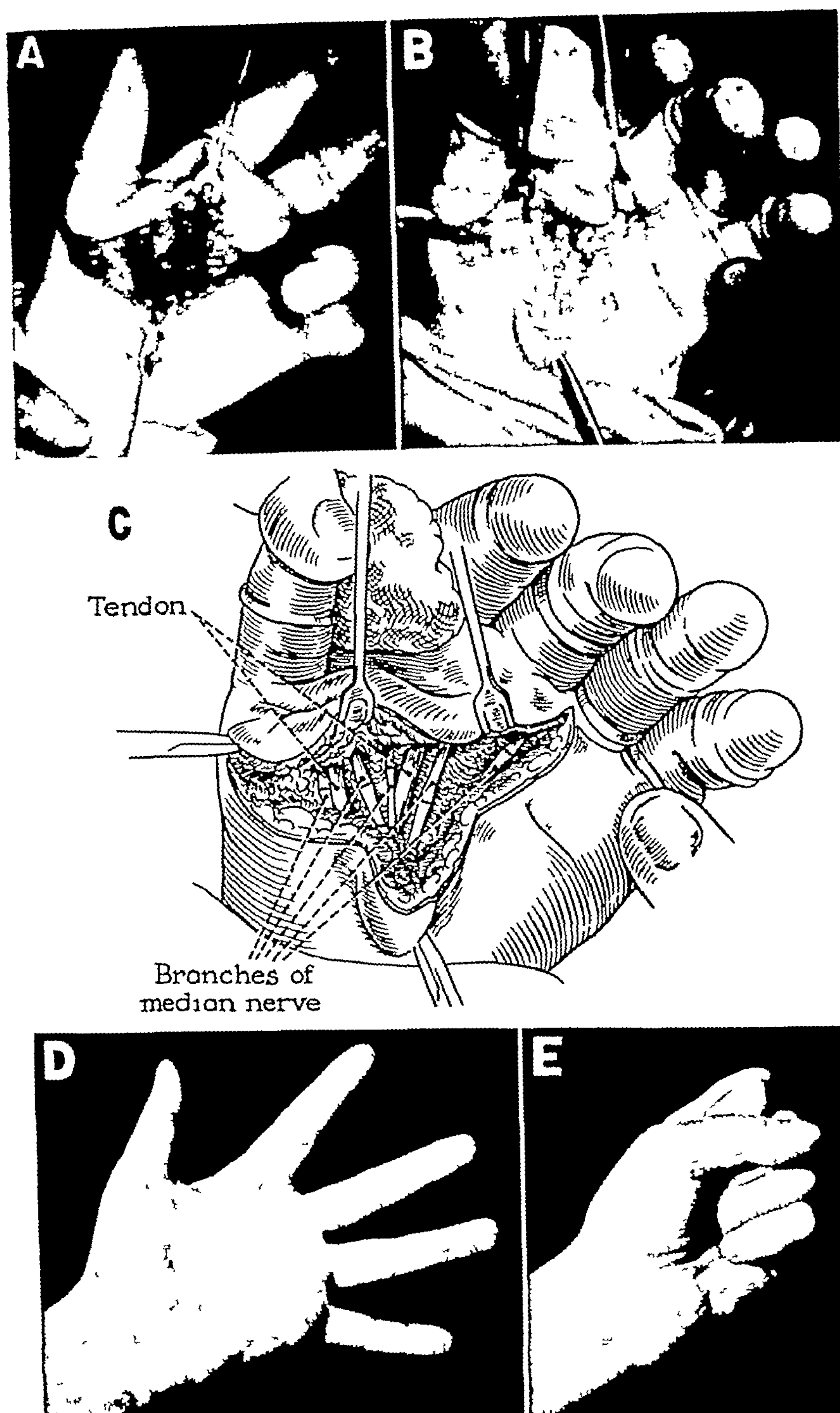


FIG 100 —*A*, injury from fall on open tin cap Deep laceration severed flexor tendons and digital nerves of thumb, index and middle fingers and three short muscles of thumb *B*, operative approach by incision along thenar crease *C*, diagram of photograph *B* *D* and *E*, full function four months later, sensation returned and the patient was able to resume vocation as a violinist.

properly carried out, however, an early return to normal function may be expected (Fig 100)

Avulsion injuries of the palm are rare and the palmar fascia is practically never torn away Crushing injuries do not usually sever tendons even though the bones are comminuted, thus, even if the tendons are exposed by such an injury they will live if they can be covered and the viability of the flaps insured It develops therefore that, other than the location of the wound, the two most important factors are contamination and the operator's skill A faulty repair may be followed by scarring so severe that further attempts at repair are almost hopeless

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fully extended when the tendon is severed, the repair will still lie in the palm, and a sufficient amount of sheath can be excised so that the healing tendon will not become abherent to a fixed structure On the other hand, if the fingers are clenched when the tendon is severed, after repair is effected the tendon juncture is inevitably drawn distally into the ensheathed area within the digit Here it will become adherent to the

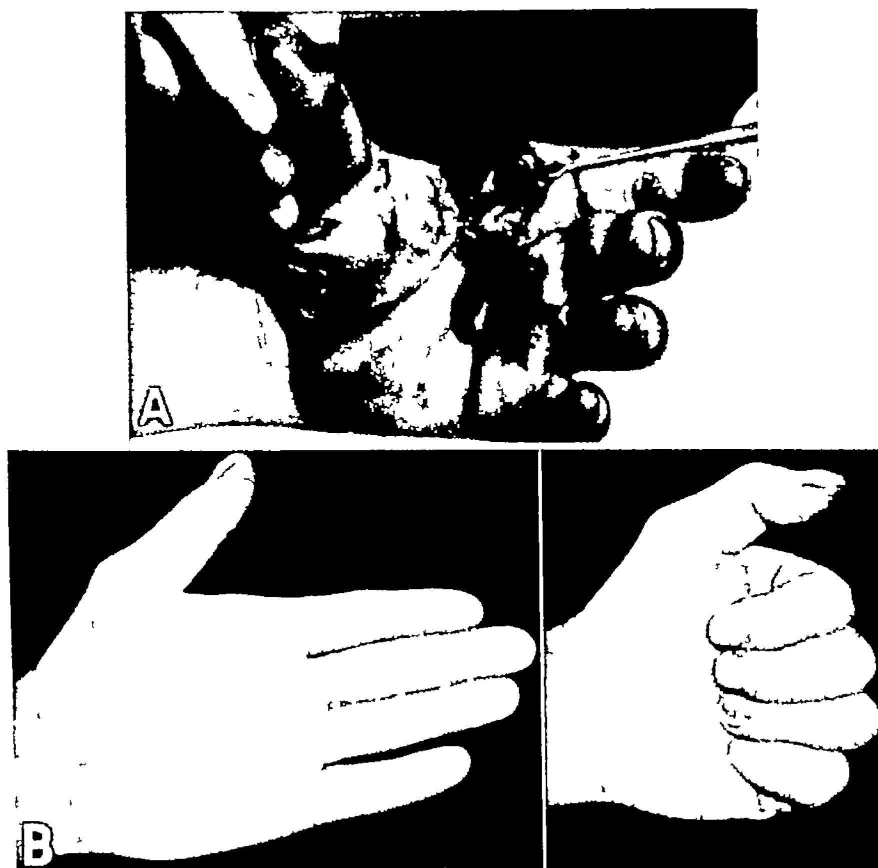


FIG 101 —*A*, extensive laceration of distal palm which severed flexor tendons and digital nerve of index finger Primary repair was done through original laceration, with excision of tendon sheath and repair of both tendons and nerve *B*, almost normal function two months later

unyielding surroundings and the repair will usually fail A successful result will be obtained if the repair lies within the palm with the fingers extended and if the tendon sheath itself is excised over the repair (Fig 101)

By careful retraction and dissection the skin is undermined over the tendon sheath and the sheath itself excised from its beginning over the metacarpophalangeal joint as far distally as the proximal flexion crease

transverse carpal ligament and forcibly flexing the wrist If several tendons are cut, pulling down on one of them will usually bring the others into view. It is usually not necessary to open the carpal canal to recover tendons severed in the palm

Any suture method which unites the tendons accurately end to end is satisfactory The thin membranous bursa or sheath which surrounds the tendon in the palm is split to make the tendon ends more accessible The choice of suture material in this region depends on the operator's preference but some form of nonabsorbable material certainly should be used Use of the pull-out technic in the palm is not necessary since remarkably good results are obtained with simple end-to-end suture and, if many tendons are cut, it complicates repair considerably

In the palm both the profundus and sublimis tendons may be repaired unless there is some definite contraindication, such as extensive damage to one of the tendons with the other remaining practically intact Although the two tendons probably do become adherent to each other during the process of healing, the end results functionally are just as good as they would be if the sublimis were sacrificed, and the grip is usually a little tighter and stronger

The lumbrical muscle is often sutured around the tendon repair in the palm Theoretically this should protect the tendon repair from becoming adherent to the palmar fascia, however in some cases reoperation has shown the muscles to be replaced by scar tissue which had become adherent to the surrounding tissues The bursa surrounding the tendon, if injured, is cut away and left open at the end of operation, if uninjured, it is closed over the repair

After the tendon repair, the branches of the median and ulnar nerves are sutured end to end, using 6–0 silk in the perineurium only Drainage is rarely indicated, The palmar fascia is not sutured separately The skin should be sutured with interrupted vertical mattress sutures which keep the edges everted These sutures should not be tied too tightly or sloughing along the wound edge may occur The edges should be matched up as accurately as possible, using the fine creases on the hand for landmarks Dressings and splinting are applied as described previously

DISTAL PALM

This region is closely related to the fingers, the tendons being enclosed in their proper digital sheaths and the cleft nerves dividing to go to each side of each digit Individual circumstances of each case determine whether or not a repair in this region will be successful If the finger is

fully extended when the tendon is severed, the repair will still lie in the palm, and a sufficient amount of sheath can be excised so that the healing tendon will not become abherent to a fixed structure On the other hand, if the fingers are clenched when the tendon is severed, after repair is effected the tendon juncture is inevitably drawn distally into the ensheathed area within the digit Here it will become adherent to the

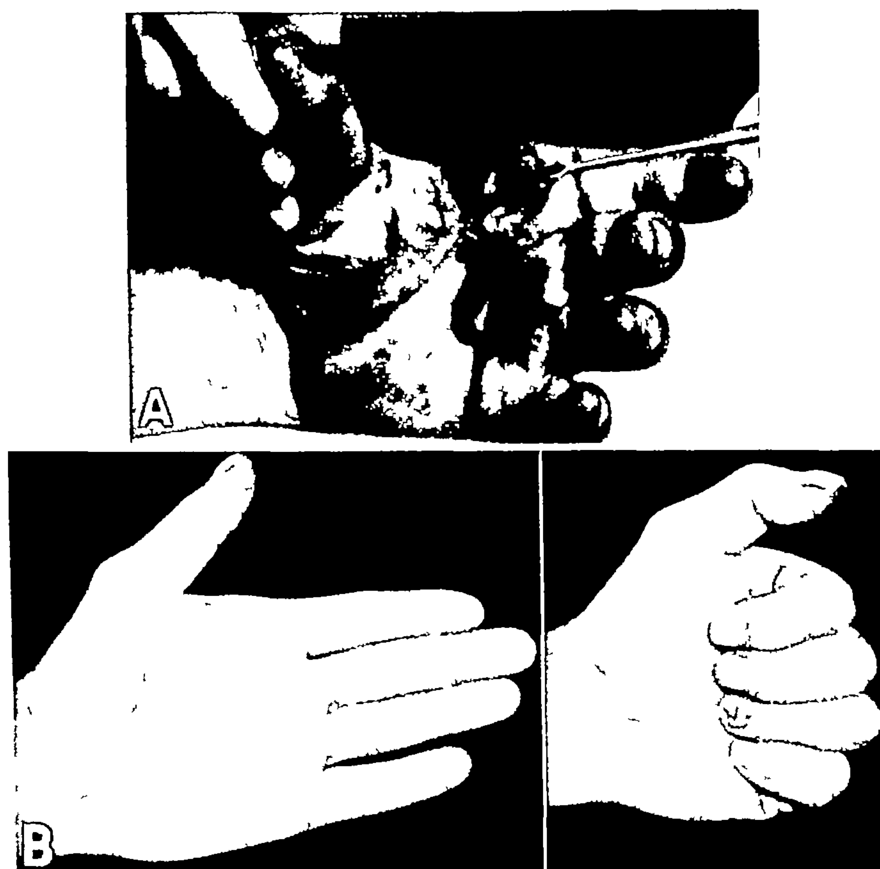


FIG 101 —*A*, extensive laceration of distal palm which severed flexor tendons and digital nerve of index finger Primary repair was done through original laceration, with excision of tendon sheath and repair of both tendons and nerve *B*, almost normal function two months later

unyielding surroundings and the repair will usually fail A successful result will be obtained if the repair lies within the palm with the fingers extended and if the tendon sheath itself is excised over the repair (Fig 101)

By careful retraction and dissection the skin is undermined over the tendon sheath and the sheath itself excised from its beginning over the metacarpophalangeal joint as far distally as the proximal flexion crease

of the finger Those cases in which the level of tendon severance is distal to the proximal flexion crease of the finger with the finger extended should be classified as digital injuries and treated as such

If the laceration is very close to the proximal flexion crease of the finger but still in the palm, primary repair, especially in children, may be done The sheath is excised both proximally and distally, the distal sublimis is excised and the profundus is recessed about ½ in into the palm

Thumb—The long flexor tendon of the thumb, when severed, often retracts excessively because there are no vincula or lumbrical muscles present. Because the tendon mobilizes only one joint, a small amount of tendon motion will give good enough function to the end joint. A technically correct primary repair will usually be successful

If the long flexor is not repaired, the interphalangeal joint gradually becomes hyperextended, the belly of the muscles in the forearm gradually contracts, producing a wide gap between the tendon ends, and the tendon sheath collapses and becomes fibrosed This makes a secondary repair troublesome On the other hand, if primary repair is unsuccessful and the tendon becomes adherent throughout its course, a secondary repair will be very difficult A secondary procedure that is usually successful, provided excessive scarring has not been produced by unsuccessful primary suture, is tendon grafting in the thumb This is usually indicated for lesions proximal to the metacarpophalangeal joint. See Chapter 13 for graft technic.

In *simple cases,* a midlateral incision is made on the radial side of the thumb and extended about 1 in proximal to the metacarpophalangeal joint, exposing the short abductor and opponens muscles and their innervation from the median nerve Any excessive dissection in this region is apt to result in loss of opposition of the thumb Through this incision the proximal end of the tendon may at times be picked up if the wrist is flexed and a fine mosquito hemostat used to reach into the proximal sheath If the tendon ends are thus recovered no further exposure is necessary Primary repair is carried out, using either the pull-out technic or end-to-end suture in the tendon The tendon sheath proximal and distal to the repair is split along its side to decompress the sutured portion of the tendon and rotated to protect the repair from the skin laceration or damaged bone (Fig 102). The skin is then sutured Dressings consist of a posterior plaster splint to keep the wrist flexed, as in repair of other flexor tendons

In *complicated cases,* the proximal end of the tendon usually retracts too far to be recovered distally and an incision in the wrist must be made

to secure it The proximal end of the thumb tendon is then threaded back through the proper channel and repaired The wrist incision may be either a short transverse or an L-shaped incision which follows the proximal crease of the wrist and turns up along the radial border of the arm The thumb flexor is a member of the profundus group and occupies the most lateral position of the deep tendons, lying just lateral to the profundus tendon of the index finger and deep to the flexor carpi radialis, the sublimis tendons and the median nerve This nerve is retracted toward the ulnar side of the arm, care being taken to protect the small sensory branch which supplies the base of the palm The tendon is identified by moving the index finger and picking up the tendon of the profundus

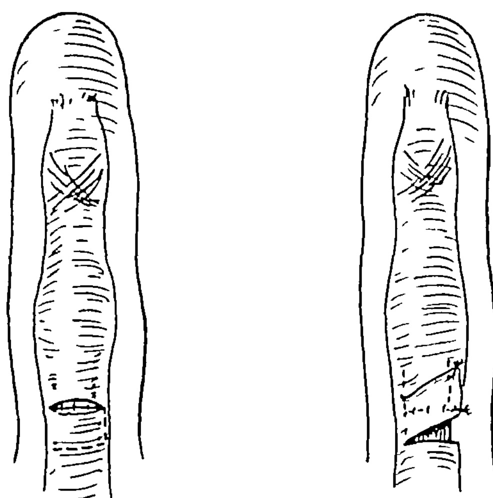
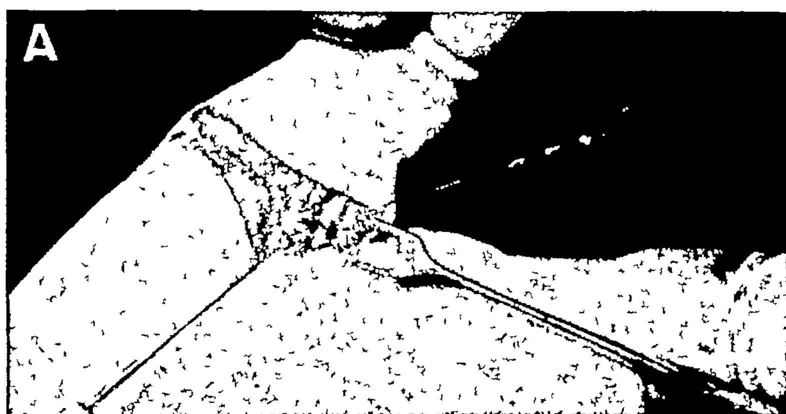
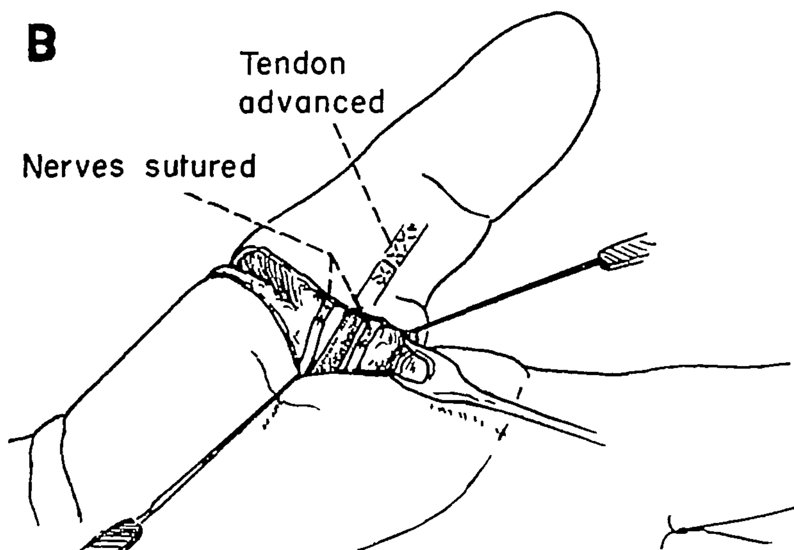
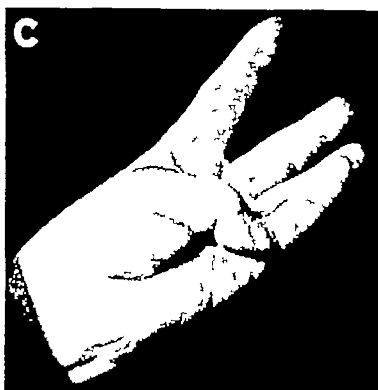


FIG 102—Rotation of flap of tendon sheath to protect tendon from skin wound Similar flap can be rotated under tendon to protect it from bare bone in secondary repairs

group which lies just radial to it The tendon is delivered into the wrist wound and a suitable suture woven into it A probe is then passed backward from the distal thumb wound into the wrist region, keeping inside the radial bursa The suture is fastened to the probe and the probe pulled out distally, bringing the tendon with it Care is taken to avoid entangling the other flexor tendons Sharp instruments should not be passed through the channel because of the danger of damaging the motor branch of the median nerve After the tendon is pulled back into the thumb wound, suturing into the distal tendon is easily accomplished with either the pull-out technic or a buried criss-cross stitch The results are better if the tendon juncture lies near the distal joint or along the proximal phalanx than if the repair lies along the metacarpal When two joints have to be mobilized, the distal joint will often have little motion For







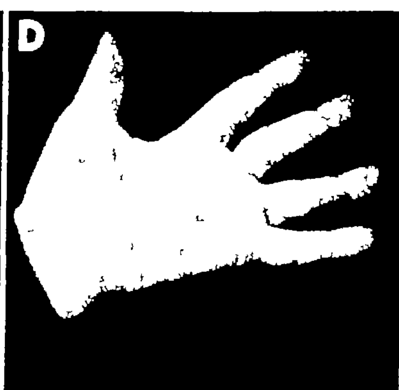


FIG 103—*A*, deep laceration at proximal flexion crease of thumb sustained in fall while holding a bottle Both digital nerves, long flexor tendon and joint capsule were severed *B*, diagram of repair; although original tendon juncture was placed away from laceration by resecting about ¾ in of tendon distally, excessive scarring required a freeing operation five months later *C* and *D*, end result

these cases it may be possible by sacrificing ½ in of the tendon distal to the juncture to place the repair in the phalangeal region where there is a better chance of function later (Fig 103) During early convalescence after such a procedure the thumb will not be completely extended, but with the passage of time function improves

Bunnell recommended an incision along the thenar crease in the palm, extending through the palmar fascia and proximally through a portion of the transverse carpal ligament The median nerve is identified and its branches in the palm identified and protected Retraction of the entire thenar eminence, including the median nerve, will expose the flexor tendon sheath of the thumb along the metacarpal region Whenever tendons are injured in this region, the operator should realize that exposure may require a long and tedious dissection, with the ever present possibility of injury to the median or ulnar nerves and with the prospect that even with the most carefully done repair adhesions will inevitably form, check-reining the tendon and impairing function For most complicated cases (Fig 177) and for wounds deep in the thenar eminence or in the carpal canal, secondary repair with grafting if indicated will give a higher percentage of good results than primary repair

Fingers.—The repair of tendons severed within the ensheathed portion in the digits has been called one of the unsolved problems of surgery Even though the surgeon has such a degree of skill that all tendon repairs in other regions give highly successful results, he will not have anything like this success in the digital sheaths Without tendon excursion of at least 1 in over the metacarpal heads, the middle finger joint is poorly flexed and the end joint not flexed at all except with the middle joint extended. The metacarpophalangeal joint is flexed actively by the interosseous muscles but this power is not strong and the function obtained is only pinch, not true grasp However carefully a tendon repair is made and whatever the technic used, some adhesions about the repair are inevitable Usually along the proximal phalanx of the finger these adhesions prevent restoration of function

PROXIMAL PHALANGEAL AREA

A number of methods to avoid trouble in this area, called no man's land, have been suggested The tendon may be given more room in its sheath by repairing the profundus, splitting the tendon sheath and excising the sublimis tendon Occasionally a good result will be obtained, but the percentage of successful repairs in this region is extremely low (Fig 104) Koch and Mason have suggested that the tendon sheath

be excised in the region of the repair, so that the tendon, when it heals, will become adherent to a fatty area rather than to the dense sheath and have a better chance to loosen up later Because the suture itself is responsible for adhesions, the suture-at-a-distance technic was devised by Bunnell In this method, the proximal retracted tendon is pulled down and is held against the distal tendon end by a suture inserted in the palm and fastened to a button in the web region The suture in the palm may cause some adhesions, but after it is removed by the pull-out wire, this part of the tendon frees itself Meanwhile, the part within the finger has united with a minimum of reaction and should free itself with exercise This method theoretically gives maximal opportunity for the

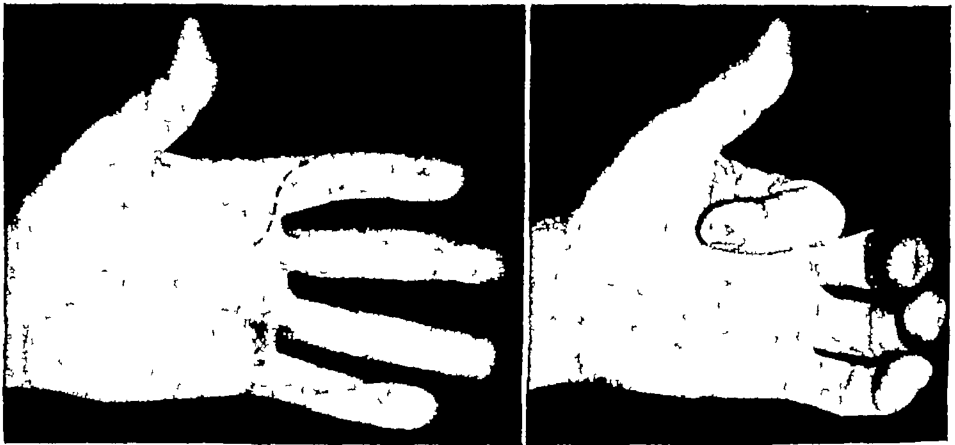


FIG 104—Unusually successful primary repair in "no man's land" Clean diagonal laceration (dotted line shows scar) across proximal segment severed both tendons and digital nerve Repair was carried out through slight elongation of laceration, the profundus tendon only being joined by a technic similar to that in Figure 87, *C*

tendon to heal kindly but is subject to the same general difficulties always encountered when a damaged tendon heals within a damaged sheath

In suturing tendon ends together within a sheath it is essential that they be joined exactly end to end with no unsatisfied tendon ends protruding Because the blood vessels supplying the tendon along the proximal phalanx are easily damaged, impaired vascularity probably plays a part in a number of complications which develop in this situation

Delayed secondary repair of tendons severed within the digital sheaths is often preferable because contamination present in the tendon sheath from the original injury is apt to cause infection, with disastrous results Furthermore, the original wound complicates the repair tendon junctures heal to it, it is not easily combined with the correct incision for exposure, etc Occasionally degeneration of the tendon takes place after

injury and can only be recognized at a secondary operation The change from an emergency procedure to an elective one makes possible proper preparation and surroundings which greatly increase the chances of success Secondary repair is, however, more difficult technically, adhesions about the tendon are usual, and the tendon sheath may have become obliterated and the muscle belly in the forearm contracted Often a tendon graft is needed to complete the repair The technic and indications for secondary repair and grafting are given in Chapter 13

Primary repair is most successful when it is possible to recover the proximal tendon ends through the original wound or through the correct midlateral incision in the finger A midlateral incision can often be placed dorsal to the primary wound Cleanly incised wounds seen within two hours offer the best opportunity for primary repair, especially if the tendons have not retracted Near the middle flexion creases there are actually three tendons in the sheath The sublimis here is often not retracted and can be restored with a few sutures of 6-0 silk The profundus can then be advanced so that its juncture lies distal to the sublimis repair (Fig 105) The sheath is always incised midlaterally as far as possible proximal and distal to the repair If possible a piece of intact sheath is slid around to protect the tendon suture line from the original wound (Fig 102)

Slightly proximal to this area, where the sublimis slips unite to form a single flat tendon, the chances of restoring independent sublimis function are less, and the results are better if the profundus alone is repaired and the sublimis excised Here again some advantage is gained if the original wound is protected by rotation of the sheath to cover the hole and/or advancing the site of the profundus juncture The primary wound should be avoided if possible

When the tendons have retracted a midlateral incision should be made in the finger and the palm then opened by an incision parallel to one of the flexion creases The crease at the base of the thenar eminence is suitable for the index or long finger, and the middle palmar crease, with the incision turning down toward the base of the palm, is suitable for the ring and little fingers The palmar incision is deepened through the palmar fascia and the tendon exposed within its sheath, avoiding the branches of the median and ulnar nerves in the palm An incision is then made in the bursa about the tendon In a fresh case, the tendon can be withdrawn into the palm without difficulty by slipping a probe under it The proximal end of the profundus tendon can be located by following the lumbrical muscle down and can then be drawn down into the hand If

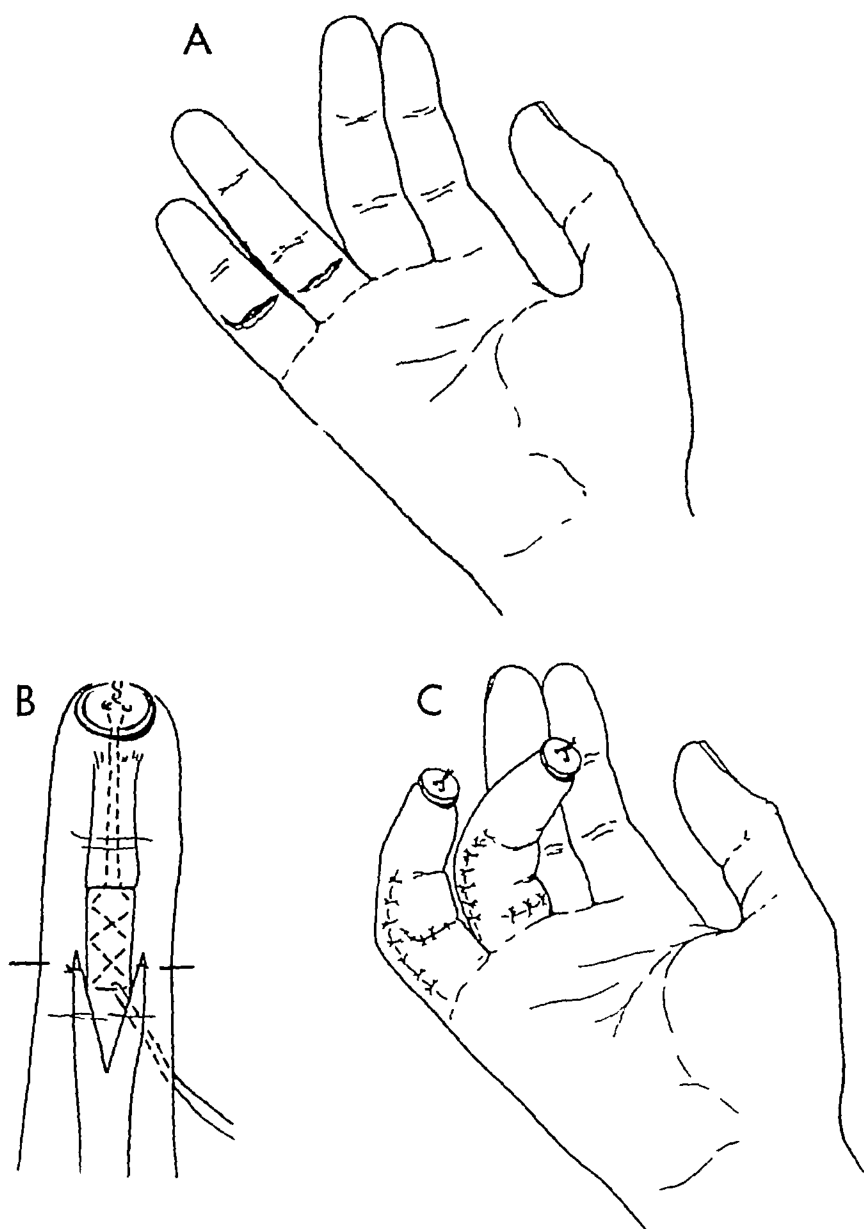


FIG 105 —*A*, typical volar lacerations of fingers with severed tendons, *B*, method of repair, advancing profundus tendon, *C*, repair completed, note location of incisions dorsal to wound

the tendon end is ragged, the ragged part may be used for traction while a suture is inserted proximal to this area. The ragged end is then excised and the suture attached to a probe which is threaded through the tendon sheath and used to draw the tendon back to its proper location in the finger where it is held against the distal tendon stump Theoretically, the suture-at-a-distance method probably is the best available for any repair made in the digital sheath From a practical standpoint, however, it is often difficult to appose the tendon ends accurately by this method, and a supplementary tack stitch at the tendon juncture is necessary Whatever method is used, the least possible amount of suture material within the tendon sheath gives best results

A great variety of materials have been suggested for use around the tendon to form a new sheath or to prevent adhesions Whatever the material, it can only succeed if it does not interfere with healing and if it eventually can be transformed into tendon-sheathlike material The use of inert, impervious material such as tantalum foil, Cargile membrane or cellophane is, therefore, contrary to all scientific facts and can only result in a failure Surrounding the tendon juncture with a free graft of areolar tissue or fat would seem to be a more sensible procedure, but these tissues are often transformed into scar tissue and retain few of their original favorable characteristics Use of a gelatin sponge about these repairs is also not recommended A gelatin sponge may be wrapped around a normal tendon and will help keep it from becoming adherent, but if placed about a tendon juncture it will cause excessive fibrosis and adhesions In doing most of these repairs the surgeon will do the least harm and get the most successful results if he keeps the technic as simple as possible The present trend is to use tendon grafts in all cases in which both tendons are cut in the proximal phalangeal area

MIDDLE PHALANGEAL AREA

In the middle segment of the finger there is considerably more chance of success of primary repairs (Fig 106) The reasons for this are that there is only one tendon, the profundus, in this area, it moves only a short distance to mobilize the distal phalanx and it is aided in its recovery by the working of the sublimis tendon which usually functions normally. In addition, the blood supply of the tendon is usually not seriously compromised With the usual midlateral incision, the proximal end of the tendon can frequently be located in the finger rather than in the palm, since it is prevented from retracting too far by the vincula It may then easily be recovered, threaded back through the window in the sublimis



FIG 106—Almost normal function six months after primary repair of flexor profundus and digital nerve in middle segment of index finger Technic was about the same as that shown in Figure 179, *A–D* (From Nichols Northwest Med 48 327, 1949)

tendon and reunited to its distal stump, preferably with a pull-out type of wire suture Distally, the wire may be fastened to a button on the end of the finger or, if the tendon juncture is conveniently close to the end of the finger, the phalanx may be drilled and the wire pulled out through the dorsum of the nail

CLOSURE

Wound closure, as after any tendon repair, should be as simple as possible The tendon sheath does not require a separate suture unless it has been completely detached from the skin, and the reconstruction of pulleys at the time of the primary repair of a fresh injury is usually unnecessary The original laceration, which was carefully debrided before the tendon repair, is carefully sutured with vertical mattress sutures of fine wire The surgical incision is then closed with a combination of vertical mattress and simple tack sutures Final hemostasis and irrigation of the wound precede closure If the midlateral incision in the finger is correctly made, the main digital artery and nerve are anterior to the incision and need not be disturbed Bleeding along the wound edges will be controlled by the closing sutures

When preoperative examination has indicated that the *digital nerves* are injured, they should be inspected after the tendon is repaired If the nerves are cleanly severed so that their ends may be accurately sewed together, repair at the time of the primary surgery will give a fairly good

functional result If the ends are torn or if one cannot tell how far back to cut to come to good nerve tissue, primary repair does little good A severed digital nerve should always be looked for when there is a laceration across the front of the finger

AVULSION OF TENDONS

Avulsions of the *extensor tendons* are almost always at the point of insertion, that is, over the dorsum of the middle and distal joints of the finger Repair of these injuries has been discussed in the section on extensor tendons

A much less common form of injury is an avulsion of a *flexor tendon* from its insertion This occasionally happens in a violent muscular effort

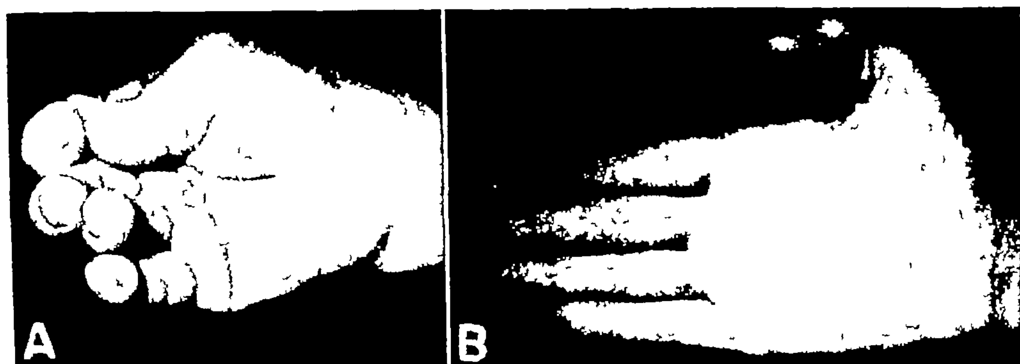


FIG 107 —*A*, injury from fall on outstretched right thumb Patient felt severe pain in wrist and later could not flex the thumb At operation the long flexor was found to have been frayed by old navicular fracture, so that it broke at this point *B*, long extensor tendon of thumb ruptured by fall Such ruptures usually occur near Lister's tubercle

in a fight, a fall on the extended finger or a similar injury The patient experiences severe pain and is unable to flex the distal segment of the involved digit Repair of such an injury is exactly the same as that for a lacerated tendon in the middle segment of the finger—the tendon is fastened back in place using a pull-out stitch woven into the tendon and passed out through a drill hole in the phalanx

The long flexor of the thumb is sometimes frayed from an old injury to the navicular bone and will rupture in this region from muscular effort or following a fall (Fig 107, *A*) Use of a graft to replace the damaged tendon is probably better in this region than direct suture although the latter has sometimes been successful The long extensor of the thumb sometimes becomes frayed over an old Colles fracture and gives way



FIG 106—Almost normal function six months after primary repair of flexor profundus and digital nerve in middle segment of index finger Technic was about the same as that shown in Figure 179, *A–D* (From Nichols Northwest Med 48 327, 1949)

tendon and reunited to its distal stump, preferably with a pull-out type of wire suture Distally, the wire may be fastened to a button on the end of the finger or, if the tendon juncture is conveniently close to the end of the finger, the phalanx may be drilled and the wire pulled out through the dorsum of the nail

CLOSURE

Wound closure, as after any tendon repair, should be as simple as possible The tendon sheath does not require a separate suture unless it has been completely detached from the skin, and the reconstruction of pulleys at the time of the primary repair of a fresh injury is usually unnecessary The original laceration, which was carefully debrided before the tendon repair, is carefully sutured with vertical mattress sutures of fine wire The surgical incision is then closed with a combination of vertical mattress and simple tack sutures Final hemostasis and irrigation of the wound precede closure If the midlateral incision in the finger is correctly made, the main digital artery and nerve are anterior to the incision and need not be disturbed Bleeding along the wound edges will be controlled by the closing sutures

When preoperative examination has indicated that the *digital nerves* are injured, they should be inspected after the tendon is repaired If the nerves are cleanly severed so that their ends may be accurately sewed together, repair at the time of the primary surgery will give a fairly good

severance of the important muscles of the thumb gives rise to loss of abduction and opposition or of adduction The interosseous muscles, except the first dorsal interossei, are rarely damaged since the bony framework of the metacarpals protects them The small muscles of the little finger may be damaged by deep cuts but loss of function here is not greatly noticed

TYPES OF INJURY—The type of injury that offers the best opportunity for repair is simple transection When a muscle in the arm is simply severed within its sheath and not otherwise damaged, in time the gap fills with scar tissue and ultimately function is restored When many muscles of the forearm are severed, adhesions develop around the individual muscle and the fascial compartments, interfering seriously with the contractility of the muscles and impairing function In the hand, where sheaths are relatively poor, the muscle ends frequently retract and do not reunite This is particularly true when the short muscles of the thumb are severed at their insertions Simple severing of a muscle does not interfere with its contractility, however, if the muscle becomes permanently contracted and the ends scarred over, no return of function is possible

A second type of injury which is not uncommon results from crushing, avulsion, tearing and fraying or grinding of the muscle fibers Under these circumstances, a considerable amount of muscle is not only damaged but is devitalized and may not only fail to heal but result in sloughing and extensive scarring This type of injury is commonly responsible for aerobic infections leading to gas gangrene, etc

A third type of injury which, fortunately, is comparatively rare occurs when the muscles are actually avulsed from their origins If the nerve and blood supplies are intact, the muscles may be replaced However, muscles that are found lying loose, attached only to their tendons distally (Fig 118), must be excised since there is no hope of restoration.

TREATMENT—*Forearm*—Injuries resulting only in laceration of the muscle require minute debridement of the wound and closure according to the principles given for tendon repairs The operator should take advantage of the fact that most muscles in the forearm are pinnate or bipinnate in structure, having a central tendinous core running most of the way up the forearm The central tendinous portion of each muscle can usually be recovered and the ends sutured together with one or two mattress sutures of wire Near the elbow the heavy common tendinous origin of the muscle may be sutured to aid in reattaching it to its origin Closer to the wrist, the fascia overlying the muscles should be split or excised to

spontaneously (Fig 107, *B*) This also responds to grafting or suturing, the projecting bony irregularity should be smoothed off

Any of the tendons may at times be avulsed from their origins In a personal case the long and short radial extensors of a child's wrist were torn away by a monkey bite These tendons have also been torn from their muscles in falls in which the wrist is caught on a projecting hook When this happens there is not much chance of restoring function by immediate repair The damaged tissues are best removed and a tendon transfer carried out according to the indications after all primary reaction has subsided Figure 118 illustrates a case

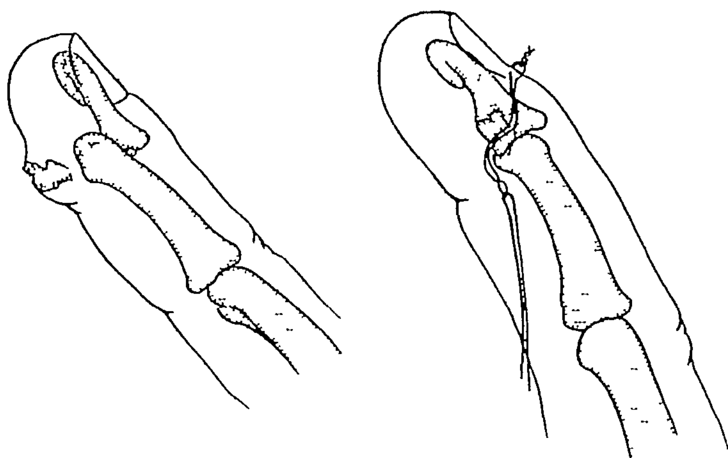


FIG 108 —Severe baseball injury with open fracture dislocation treated by pull out technic

Professional baseball catchers who do not keep their ungloved hands flexed are subject to a severe type of splitting injury of the finger when struck by a foul tip An open fracture dislocation results, with the volar fracture fragment pulled away from the joint by the flexor tendon These injuries can be repaired by internal fixation with a pull-out wire to hold the tendon (Fig 108)

MUSCLE INJURIES

Muscles proximal to the musculotendinous junctions in the forearm may be lacerated and contused by penetrating or crushing injuries In the hand the thenar and hypothenar muscles may be damaged by similar injuries These wounds may be minor or of the most major proportions

In the forearm, lacerations of the muscles result in weakness of finger or wrist motions, depending on which elements are severed In the hand,

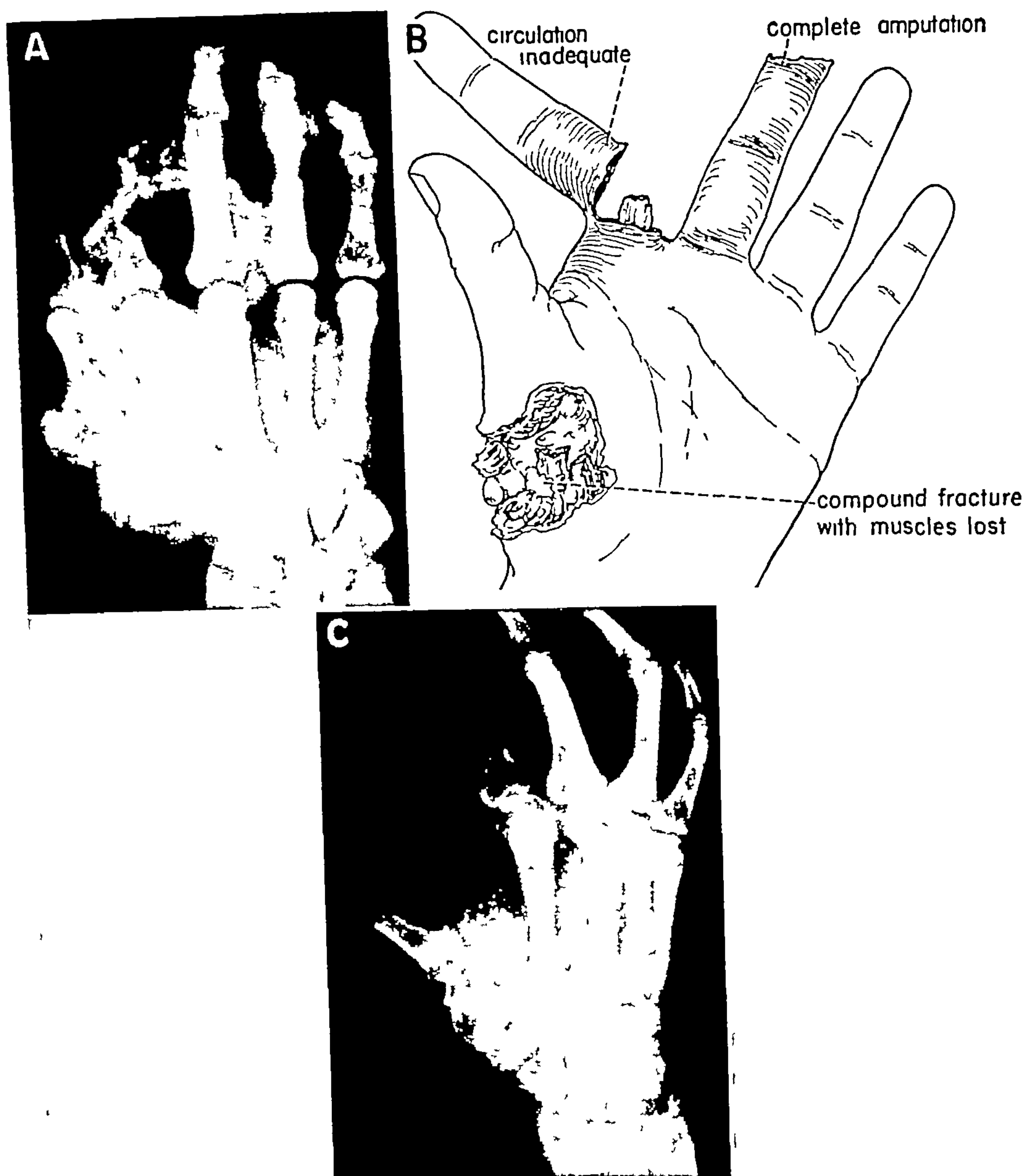


FIG 109 —Hand caught in coffee grinder, with loss of index finger and tip of long finger and destruction of most of thenar muscles and thumb metacarpal *A*, x-ray and *B*, diagram of injury Treatment included debridement and loose closure of wound, hand was kept in position of function and wet packs and antibiotic therapy were used *C*, x-ray of end result, hand is useful although thumb is about 1½ in short

allow the muscle to swell and to prevent adhesions which would interfere with function later

In the second type of injury in which much muscle is damaged, repair becomes more complicated because every bit of devitalized muscle must be excised before the wound is closed Viable muscle is always contractile and can be recognized by its blood supply and color Devitalized muscle does not contract, does not bleed when cut across and has a darker color Patients with this type of injury require prophylactic therapy against gas gangrene and tetanus and careful postoperative observation Splinting is essential At the appearance of signs and symptoms of gas gangrene—swelling of the wound, crepitation beneath the skin, pain and a dusky cyanotic color—further excision of tissue or amputation may be indicated. In selected cases the involved group of muscles may be excised and the extremity preserved Suitable reconstructive procedures are carried out months afterward to restore function

Hands—The short muscles of the thumb, when severed, are amenable to primary repair if the wound is otherwise clean Minute debridement should be carried out and the muscles then repaired using a series of mattress sutures of catgut The aim is to restore the bulk and continuity of the muscle without adding much foreign suture material which interferes with healing and without producing any additional trauma There is no sliding problem such as that encountered in tendon repair Splints should be applied to relax the pull of these muscles whenever possible When the muscles in the hand are cut away from their insertions, the tendinous ends may be fastened back into place with wire sutures run through drill holes in the bone if necessary

In the more severe crushing and avulsing type of injury (Fig 109), an economical debridement is done The skin should then be loosely closed with drainage and splinting applied So much soft tissue injury is present in these cases that there is usually some sloughing of the wound The wound stabilizes after prolonged hospital care, with wet packs, daily dressing and antibiotics Skin grafting may be necessary, either primarily to obtain wound closure or after granulations are formed

Some of these cases offer an excellent opportunity for secondary repair For example, the abductor and opponens may have been severed from their insertions and not function but can be felt to contract They can be dissected out of their sheaths and the distal scarred ends brought down and partially returned to their insertions, using a small fascial sling or split-off portions of the extensor tendon of the thumb for anchors

The degree of success in the restoration of muscle function depends on

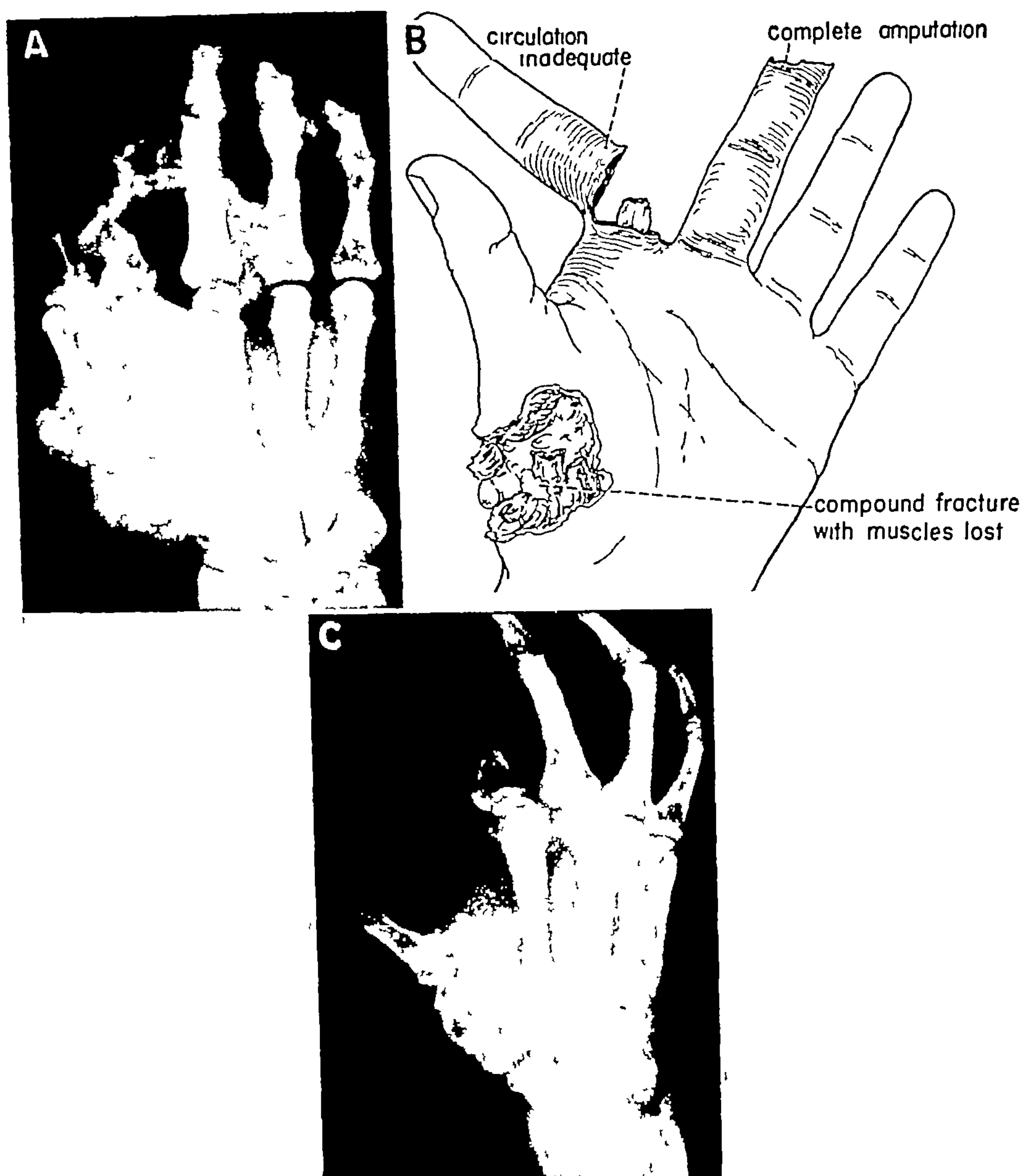


FIG 109 —Hand caught in coffee grinder, with loss of index finger and tip of long finger and destruction of most of thenar muscles and thumb metacarpal *A*, x-ray and *B*, diagram of injury Treatment included debridement and loose closure of wound, hand was kept in position of function and wet packs and antibiotic therapy were used *C*, x-ray of end result, hand is useful although thumb is about 1½ in short

the amount of scarring which follows the original injury In thumb web contractures which follow trauma, the short muscles are found to be completely replaced by tight fibrous bands There is no means to avoid this in some crushing injuries, and restoration of the thumb web by the pedicle method will be required at a later date In some forearm injuries in which restriction of motions, especially of extensor muscles, is such that function is partially interfered with, a secondary exploration is indicated Scar tissue must be excised if possible without interfering with the continuity of the muscle, and the soft tissues should be restored by the pedicle method, using an abdominal flap Usually, even without such a repair, there is slow restoration of function, and some improvement may be expected even 12 months after the original injury

There is a remarkable ability of the small muscles in the hand to regain their function, provided they are not completely destroyed and primary repair is adequate Even the lumbrical muscles apparently regain some function unless they are hopelessly chewed up, and the thumb muscles, unless deprived of their nerve supply or extensively comminuted, may also recover

CHAPTER TEN

Nerve Injuries

NERVES SUPPLYING the forearm and hand are injured more often than the average surgeon realizes Frequently, in more complicated wounds a nerve is injured along with tendons and other soft tissues but the lesion is not recognized and proper treatment is not carried out Months then go by before any repair is attempted After a nerve is severed, the muscles it supplies undergo atrophy and fibrosis The progress is fairly rapid and at the end of a year only 50 per cent of the muscles remain It is therefore extremely important to repair the injured nerve at an early date

ETIOLOGY

SUBCUTANEOUS INJURIES—Nerves are quite tough and are rarely severed subcutaneously by blunt violence Occasionally, however, sufficient bruising occurs to give rise to symptoms of interruption The *median nerve* is damaged during forcible attempts to reduce a dislocated semilunar bone in the wrist, the nerve being caught between the projecting bone and the surgeon's fingers * The median nerve is also sometimes damaged subcutaneously in severe Colles' fractures It may be damaged by a crushing injury of the wrist In the forearm, the median nerve is protected by the sublimis group of muscles and blunt violence or even severe compound fractures rarely result in a nerve injury. However, at the elbow it may be damaged from a supracondylar fracture of the humerus A direct blow rarely causes injury here since the nerve is protected by the lacertus

* Recent reports indicate that median nerve palsy following dislocation of the semilunar bone may be due to excessive stretching of the nerve rather than to bruising.

fibrosus and the biceps tendon which stand anterior to it in this region.

The *ulnar nerve* is frequently damaged at the elbow by fractures or dislocations or by being bruised in the bony groove of the median epicondyle It may also be damaged by sudden violent extension of the arm

The *radial nerve* is almost never injured subcutaneously in the forearm However, above the elbow the commonest nerve injury is that to the radial nerve where it winds around the humerus in the musculospiral groove The injury here is produced by fracture of the humerus, the nerve being either torn apart or bruised by the bone ends Injury to the radial nerve in the upper arm is often due to compression of the nerve over the arm of a chair, the so-called "Saturday night paralysis"

LACERATIONS—The injury which most commonly causes severance of a nerve is a laceration inflicted by a sharp-edged object, such as a knife, glass or tin can In any penetrating wound of the hand a nerve injury should be suspected and the necessary examination to ascertain its presence made Arterial bleeding on the volar surface of the finger or the ulnar border of the forearm should arouse suspicion that the nerve which accompanies these arteries has been severed along with the artery Similarly, whenever tendons in the palm or digits are divided by cutting injuries or even with a superficial cut on the radial or ulnar side of the palm, some branches of the median or ulnar nerve are apt to be severed

The *ulnar nerve* in the wrist and lower half of the forearm occupies a more vulnerable position than the median nerve, being only partly covered by the flexor carpi ulnaris Consequently, in the hand and forearm this nerve is less frequently injured subcutaneously than is the median nerve but is more commonly injured by direct trauma A fall on a circular saw, for example, which results in an open fracture of the ulna will often sever the ulnar nerve Any laceration which severs the ulnar artery will usually also sever this nerve At the elbow, in the groove behind the medial epicondyle, the ulnar nerve is particularly subject to trauma, and any small laceration, such as that from a fall on a splinter of glass, may completely sever the nerve

Either the *median nerve* or the ulnar nerve is almost always injured in lacerations of the wrist which are deep enough to sever the wrist flexor tendons When the palmaris longus is cut in a penetrating wound, the median nerve should always be examined in the course of wound repair since this tendon is commonly mistaken for the median nerve The median nerve may also be injured by penetrating wounds in the carpal region, and its branches are often injured in puncture wounds of the palm, such as those produced by the breaking of a porcelain handle on a faucet The

median nerve together with the ulnar is damaged in deep transverse lacerations into the muscular part of the forearm and in lacerations in the upper arm which may sever the brachial artery.

Injury to the sensory branch of the *radial nerve* in the forearm or wrist is often not detected because this branch supplies only sensation on the dorsum of the thumb and index and middle fingers, and this can be partly taken over by overlap from adjacent nerves Lacerations of the snuffbox region or of the radial aspect of the dorsum of the forearm may sever this nerve, especially if the extensors of the thumb are severed at the snuffbox or the brachioradialis is severed in the forearm The deep motor branch of the radial nerve may be injured by a fracture just distal to the head of the radius or by a surgical approach in this region It is also severed by deep lacerations on the back of the upper forearm

Damage to the median or ulnar nerve above the elbow is uncommon except by gunshot wounds, knifings or injuries to the shoulder with resultant brachial plexus tears Occasionally any of the nerves along with other soft tissues and tendons may be avulsed from either the fingers, hand or forearm This condition is particularly confusing to the surgeon because the landmarks by which these structures are identified may be missing Severe infections of the deep structures of the forearm with prolonged suppuration are apt to be followed by median or ulnar nerve palsies Electric burns likewise cause severe and often permanent damage to nerves

DIAGNOSIS

EXAMINATION OF THE HAND—By pricking the tips of the fingers one can establish immediately whether the median or ulnar nerve or their sensory branches have been severed (Fig 110) A severed digital nerve in the front of the finger causes a loss of sensation in the corresponding side of the finger pad More proximally in the palm, the branches to the clefts when severed will give rise to anesthesia on adjacent sides of the digits When several of these are severed, the area of anesthesia may approach that to be expected if the whole nerve is severed, but usually this area will not exactly correspond

Motor branches—The motor branches of the median nerve lie at the base of the thenar eminence where they may be damaged by penetrating wounds When the nerve is severed, the patient cannot abduct or oppose the thumb because of paralysis of the short abductor and opponens muscles The thumb then cannot make a good pinch and tends to roll into adduction A certain amount of pseudo-opposition may at times be present,

but in pinching strongly the thumb will assume the adducted position If the long flexor tendon has also been cut, so that the pinch test cannot be carried out, the opponens may be palpated when the patient is asked to abduct the thumb against resistance This test is wholly reliable if carefully carried out

The motor branch of the ulnar nerve supplies the interossei and the adductors of the thumb as well as the short muscles at the base of the little finger which are more or less a mirror image of those about the thumb Testing for this nerve is best carried out by having the patient spread the fingers and bring them together again while still extended

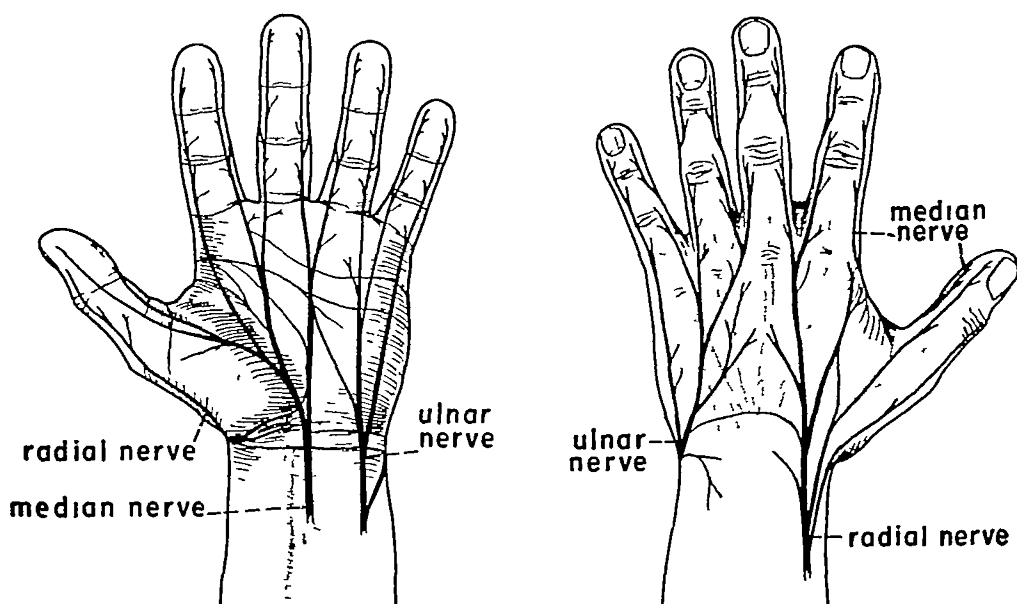


FIG 110—Cutaneous branches of median, ulnar and radial nerves on palm and dorsum of hand

Sometimes the fingers can be spread by the long extensor tendons, however, they cannot be spread and then brought together while extended except by the interossei Another good test for this nerve is to palpate the first dorsal interosseous muscle while the patient pinches the index finger against the thumb This muscle is easily palpated when it contracts If either the median or ulnar nerve is severed proximal to its motor branch, the signs produced are those of combined sensory and motor dysfunction

Some difficulties in initial diagnosis of median and ulnar nerve injuries are due to anatomic variations in the innervation of the small muscles of the hand The first dorsal interosseus may be supplied by the median nerve and, occasionally, the ulnar nerve supplies the whole of

the thenar musculature as well as the rest of the small muscles of the hand. Since exploration is almost always indicated anyway, interest in these anatomic variants is more academic than practical.

Sensory branches—The sensory area covered by the median nerve as usually described includes the volar surface of the thumb, index and middle fingers, one-half the ring finger and all the palm on the radial side of the ring metacarpal extending proximally as far as the base of the

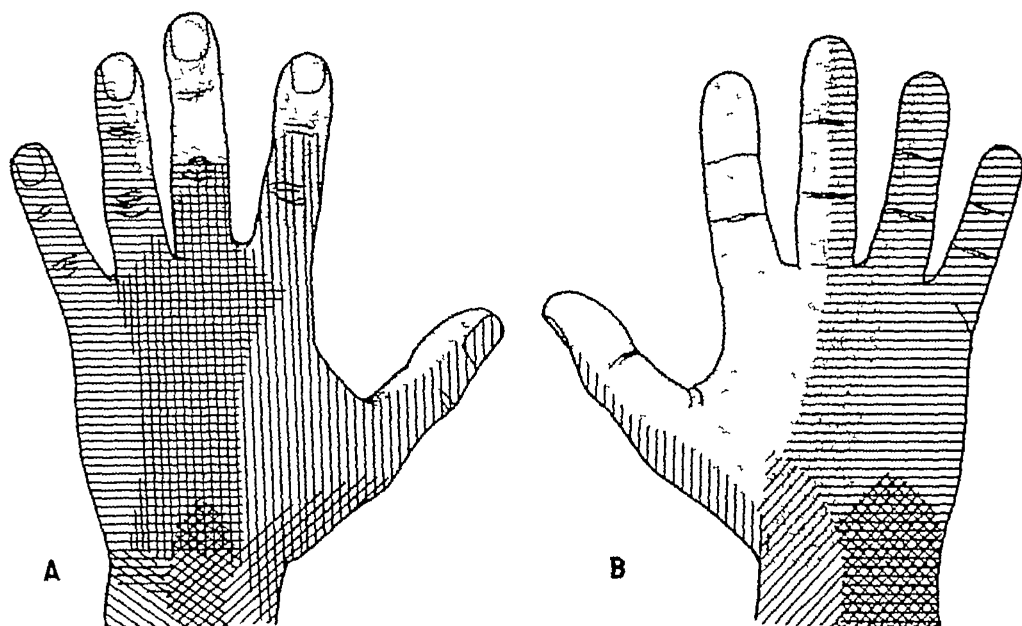


FIG 111—Cutaneous sensory distribution of *A*, dorsum of hand and *B*, palm Stippled areas, median, horizontal lines, ulnar, and vertical lines, radial nerve, left oblique lines, lateral antibrachial cutaneous (musculocutaneous), right oblique lines, median antibrachial cutaneous nerves Dorsal antibrachial cutaneous overlap is shown in middle of wrist in *A* The musculocutaneous, median antibrachial cutaneous and the palmar cutaneous branch of the ulnar overlap the median and ulnar areas on the volar surface of wrist On the dorsum, the musculocutaneous overlaps the radial nerve Anomalies are common on the dorsum, and either the radial or ulnar may supply the entire surface or their places may be taken by the overlapping cutaneous nerves from the forearm, average overlap is shown here

thenar eminence (Fig 111) It also includes the dorsum of the distal segments of these digits The sensory branches of the ulnar nerve supply the rest of the volar surface of the hand and, through the dorsal branch given off above the wrist, the skin of approximately one-half the dorsum of the hand with the exception of the area over the distal segments of the digits This is supplied by the volar branches

Whereas this arrangement is present in a large proportion of individuals, it must be kept in mind that it is not uncommon for the ulnar

nerve to supply the palm as far as the middle metacarpal and the adjacent sides of the ring and middle fingers In this circumstance the median nerve supplies a correspondingly smaller area

On the back of the hand the sensory nerves fan out from the wrist in such a way that the main branches are rarely severed and the smaller branches, when severed, produce rather indefinite areas of anesthesia. This

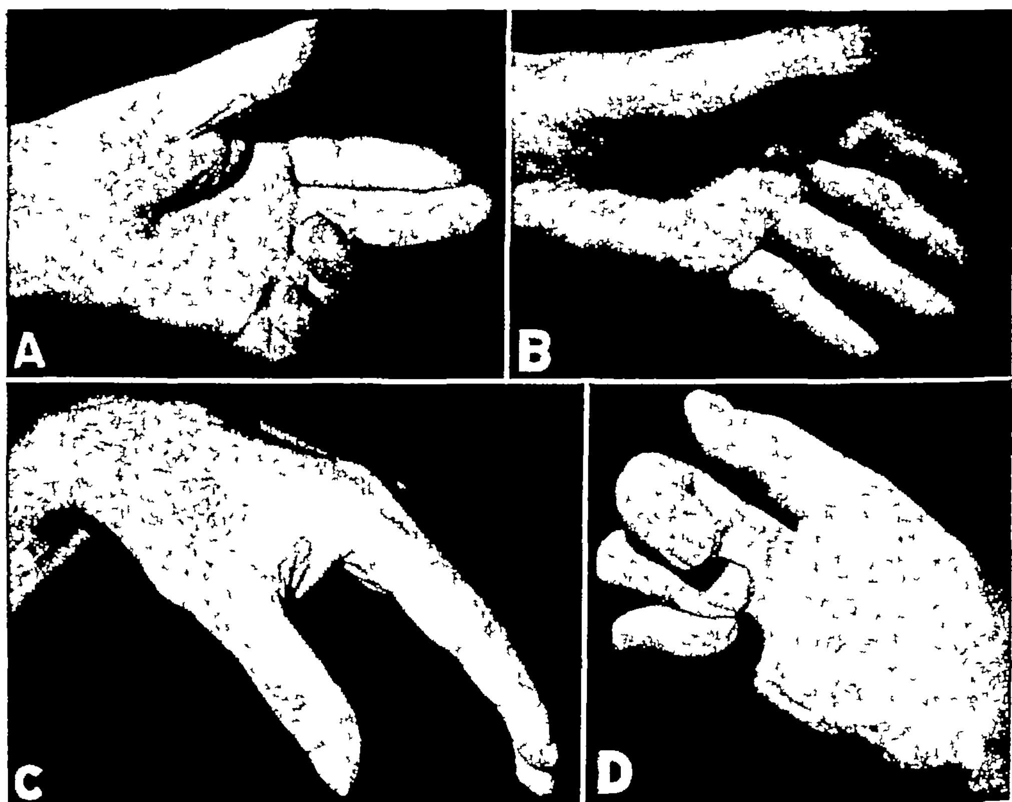


FIG 112 —*A,* ulnar nerve palsy, with contracture of ring and little fingers and atrophy of hypothenar muscles *B,* median nerve palsy, with adduction of thumb and atrophy of thenar muscles *C,* radial nerve palsy with pronounced wrist drop *D,* combined median and ulnar nerve palsy, showing clawing of hand

is due to overlap from the volar nerves and to overlap locally of the radial and ulnar nerve branches Loss of sensation is obviously less important on the dorsal than on the volar surface

EXAMINATION OF THE FOREARM (Fig 112) —The *ulnar nerve* runs through the forearm without giving off any muscular branches, thus, symptoms produced by severing it are the same anywhere between the wrist and the elbow Just below the elbow the ulnar nerve gives off two muscular branches which supply the flexor carpi ulnaris and the ulnar half of the flexor digitorum profundus When the nerve is severed above

this region the patient will be unable to flex the distal segments of the little and, at times, the ring fingers The ulnar nerve also supplies the lumbricales and the interossei to these same fingers Hence, when the ulnar is severed in the wrist, the fingers are later drawn down toward the palm in the middle and end joints and hyperextended at the proximal joints However, when it is severed at the elbow or above, the flexion contracture involves only the middle joints This contracture is usually more pronounced in the little finger than in the ring finger

The *median nerve* muscular branches supply all the superficial muscles on the volar surface of the forearm except the flexor carpi ulnaris. The deep forearm muscles, except the ulnar half of the flexor digitorum profundus, are supplied by the volar interosseous branch of the median nerve which arises just distal to the pronator teres and descends in the forearm along the front of the interosseous membrane It will be seen that the median nerve may be severed rather high in the forearm without necessarily interfering with the innervation of the forearm muscles. In fact, this is usually the case unless the wound is very deep, such as that inflicted by a circular saw or a heavy cutting object. If the volar interosseous branch is injured, inability to flex the distal joints of the thumb and the index and middle fingers will result, and there will be some weakness in pronation due to paralysis of the pronator quadratus If the nerve is damaged at the elbow or above, all the flexor muscles in the forearm except the flexor carpi ulnaris and ulnar half of the flexor profundus will be paralyzed (See Fig 5.)

When the motor branch of the *radial nerve* is injured by wounds about the elbow or on the dorsum of the forearm, the extensor muscles are paralyzed and the degree of wrist drop produced depends on whether the complete nerve or only some of its branches are severed As the nerve winds around the neck of the radius, it passes through the supinator muscle; if severed in this region (as by surgical excision of the head of the radius), all the extensor muscles will be paralyzed except the brachioradialis which is supplied by a branch arising above the elbow. In this situation there is complete inability to extend the thumb, the digits or the wrist (See Fig 6)

A short distance below this point a large branch of the nerve is given off, which supplies the extensors of the wrist and the common extensor muscles of the fingers Injuries in this location are not common because the nerve is heavily protected with muscle Distal to this point a deep laceration across the back of the arm may damage the small deep branch of the radial nerve which extends down the middle of the dorsum of the

forearm between the deep and superficial groups of muscles. Injury to this nerve results in inability to extend the thumb or to extend the index finger separately. In repairs of deep lacerations on the back of the forearm, this nerve is usually overlooked because it is small and the multiplicity of structures present, including muscles and tendons, makes it difficult to find.

Complicated cases.—No surgeon who sees many hand cases can fail to be impressed with the variety of complaints produced by nerve lesions. In fresh cases the signs are much less severe than later, after secondary joint changes and muscle contractures have occurred. For example, in a recent ulnar nerve motor palsy the patient can extend the fingers normally if the hand is placed with the dorsum against a flat surface to stabilize the metacarpophalangeal joints. In old cases of combined median and ulnar palsy the typical claw hand (Fig. 112, *D*) is the result of intrinsic muscle paralysis plus secondary joint and muscle contractures. Tardy palsy of the median nerve by compression in the carpal tunnel is often missed in diagnosis because the patient forgets to report the original injury; a similar situation exists with regard to the ulnar nerve at the elbow.*

In any suspected peripheral nerve lesion a brief neurologic survey should always be made to rule out generalized neurologic disease, central nervous system lesions and lesions in the neck. Neck lesions include cervical ribs, protruding cervical discs, brachial plexus neuritis and progressive muscular atrophy.

PATHOLOGY

Degeneration.—When a nerve is severed there results not only anesthesia of the sensory area supplied and paralysis and subsequent fibrosis of the muscles but trophic changes as well. The skin of the extremity becomes smoother and less elastic, vasomotor changes take place, joints stiffen and bones become demineralized. The nerve itself degenerates distal to the point of injury, and the proximal end develops a bulbous, rounded neuroma from which small nerve fibers emerge in a tentacle-like fashion and attach themselves to the surrounding scar tissue. If repair is not effected, the nerve distal to the injury gradually becomes fibrotic, its sheath thickens and the nerve elements within it first swell and later contract down as scar tissue replaces nerve tissue. Prolonged delay in repair of injured nerves results in irreversible changes, and much avoidable damage may follow unnecessary procrastination.

* See Chapter 14 for operative treatment of these conditions.

HEALING.—If the nerve is sutured and its ends unite satisfactorily, regeneration of the fibers can be expected at the rate of approximately 1 in. a month. Thus, regeneration from the wrist to the finger tips will usually take six to eight months, and from the upper forearm, a year and one-half may elapse before sensation returns to the finger tips. During all this time the various trophic changes are taking place.

Nerve sutures are rarely perfect because it is almost impossible to match the ends exactly. This is particularly true of the large nerves in the forearm and wrist and to a lesser degree of the digital nerves in the fingers.

After a nerve is severed a certain amount of ingrowth of fibers from the other nerves surrounding the area of anesthesia gradually takes place, reducing the area of sensory anesthesia. This phenomenon gives the impression that the nerve is regenerating. At times, blocking of the intact nerves with procaine is necessary to determine whether or not regeneration has actually taken place.

Even when a nerve is cleanly cut and carefully repaired immediately, a certain amount of neuroma production always occurs, and afterward there are swelling and disalignment of nerve fibers at the point of repair. If the nerve is torn apart, the fibers are stretched, causing damage a considerable distance from the point of separation. Under these circumstances, extensive fibrosis results and regeneration is retarded or may never occur.

TREATMENT

The need for treatment depends on the degree of injury present. If a nerve is contused (neurapraxia), there is impairment of conductivity with incomplete paralysis and loss of sensation. Recovery takes place within a few days or weeks. When the axons are actually injured (axonotmesis), spontaneous recovery results as the nerve grows back down through the Schwann tubes, a process which takes several months. If the nerve is completely severed or disorganized (neurotmesis), however, recovery is impossible without repair. Surgical exploration is frequently indicated when the exact status of the nerve cannot be determined.

One of the most difficult problems arises when the nerve is only partly severed. Here the ability to use and interpret the electrostimulator is indispensable. In partial disruptions of mixed nerves, such as the ulnar, good motor response to stimulation may, at times, deter the surgeon from attempting a repair. The added advantage of returning sensation to the little finger may not be worth while, compared to the technical difficulties encountered in doing a partial neurorrhaphy, especially at the branching

end of a nerve, when the remaining nerve fibers are caught in dense scar. This situation applies more in late secondary repairs than in fresh injuries

Primary vs. secondary repair—Whether primary or secondary nerve suture is best is a perennial question A number of uncorrelated factors, such as apparent spontaneous regeneration, improper surgical technic,

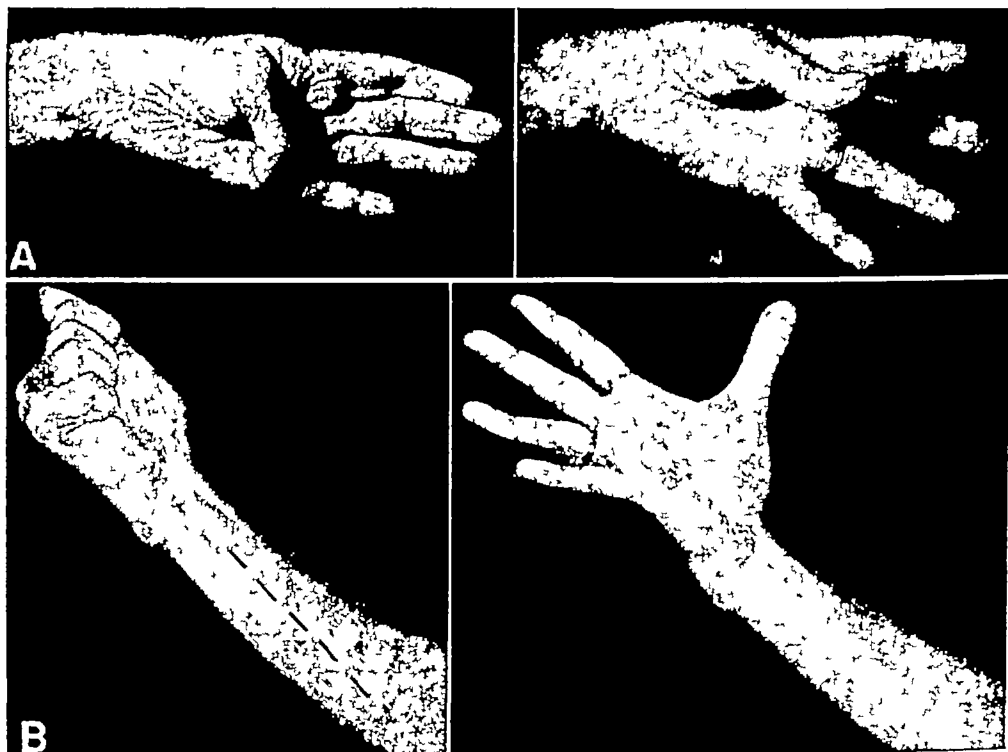


FIG 113—*A,* complete recovery of small muscles of thumb after primary repair of median nerve at wrist, sensation to cotton wisp, heat and cold and stereognosis almost normal *B,* almost complete recovery of sensation and of small muscles of hand after primary repair of ulnar nerve in forearm (broken line shows surgical scar)

improper choice of cases and improper evaluation of end results, contribute to this confusion

In World War II, when most nerve injuries were caused by missiles, it was found that early secondary repair almost always gave better results than primary suture The reasons for this were that the average operator probably was not able to recognize the exact extent of the damage proximal and distal to the site of injury and the Schwann cells of a regenerating nerve do not attain as much activity right after injury as they do later From the technical point of view, secondary suture is easier because the epineurium has become thickened and because, without the danger of infection, the nerve may be mobilized to a greater degree Secondary su-

ture converts the operation from an emergency procedure done under difficult surroundings to an elective one under ideal conditions The experience of individual operators is somewhat at variance with this mass experience If a nerve is cleanly severed and is properly repaired at once by one who is expert in the technic, there is no reason why a good result should not be expected (Fig 113)

The *indications and contraindications* to immediate repair must be considered carefully in any wound on the forearm or hand in which the diagnosis of nerve injury has been established If the wound is clean or can be rendered clean surgically and the nerve injury is purely local, a technically correct primary repair will give the best results If the nerve has been damaged for a considerable distance or if kindly healing of the wound can obviously not be expected, it is probably worthless to attempt neurorrhaphy at this time Similarly, a nerve stripped of its blood supply for a considerable distance will probably not regenerate well, and primary suture should not be attempted Under these circumstances it is better to postpone repair for about a month or until the primary wound is free from reaction The nerve may then be dissected out and the damaged part will be more apparent and can be more accurately removed

When secondary nerve repair is to be done, immediate treatment consists of simple closure of the original wound, with the nerve placed in its correct anatomic position One good-sized black silk suture is used to tack the nerve ends together. This helps to identify the nerve at the secondary repair

Primary Nerve Repair

To expose a nerve in the hand, the surgeon should use the same technic as that for approaching tendons (see Figs 86 and 114) The incision should be placed so as to avoid scar contractures and their damaging effects, and the nerve should be approached without exposing the easily damaged surface of the tendons any more than necessary The incision should not cross flexion creases because this invariably leads to a hypertrophied scar Use of a tourniquet on the upper arm, as described in Chapter 2, produces a bloodless field and greatly facilitates the operation

In digits—In the finger a midlateral incision should be used This incision is deepened to the deep fascia overlying the tendon and bone, and the full thickness of the skin and subcutaneous fascia can then be reflected toward the palm The digital nerve is then easily picked up in the fat chamber on the anterolateral quadrant of the finger Fresh wounds which sever a digital nerve in a finger are usually transverse lacerations To un-

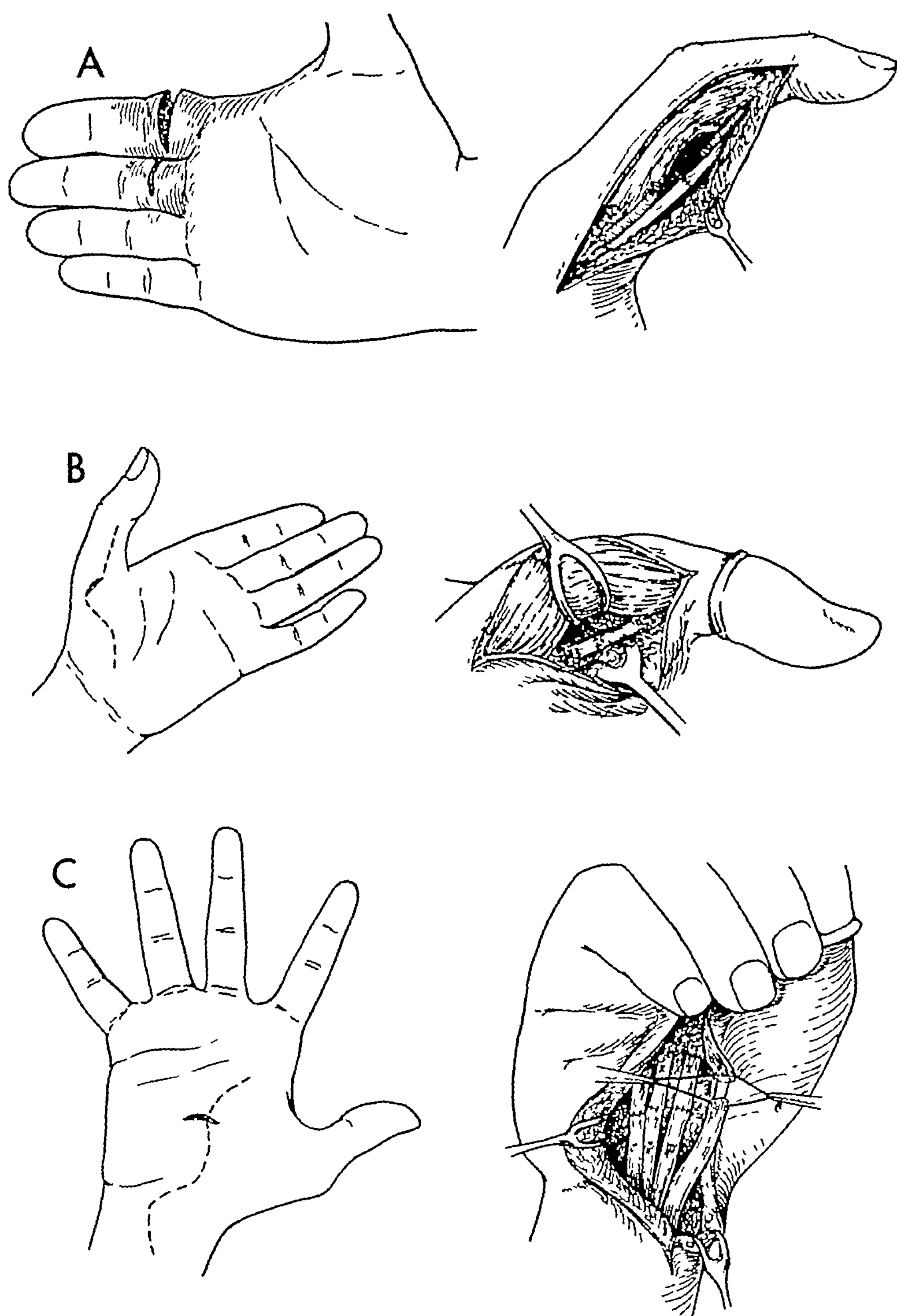


FIG 114, PLATE 1 —Nerve repair incisions, drawn from photographs of actual cases (see text for technical details) *A*, digital nerve in index finger, *B*, digital branch in thenar eminence, *C*, median nerve and tendons in carpal tunnel

cover the nerve, an incision may have to be made from the end of the laceration along the midlateral line proximally and distally The resultant T-shaped incision does not give perfect wound healing (See Fig 114, Plate 1, *A*)

The digital nerve is about 1/16 in or more in diameter After exposure, it can easily be picked up and sutured, using 6–0 or 7–0 silk on an atraumatic needle and placing the sutures in the perineurium only On the average, about four sutures are sufficient The nerve should be handled as gently as possible, being picked up by a fine pincette type of forceps.

IN THE PALM —When a nerve is injured by a laceration in the palm, the incision to expose it is like that used to expose tendons The original laceration can be extended by an incision which parallels the flexor creases and turns down toward the base of the palm in a line between the median and ulnar distribution along the middle of the fourth metacarpal if necessary This incision will give excellent exposure to any of the branches of the *median nerve in the palm* (see Fig 100), including the important motor branch which comes out from underneath the transverse carpal ligament and turns immediately into the small muscles of the thumb Approximately the same technic should be used in repairing the digital nerves in the palm as in the fingers, four or five sutures in the perineurium being all that is necessary to hold the nerve ends together

At the base of the palm where the median nerve passes under the transverse carpal ligament, the branches come together The motor fibers separate from the sensory fibers about ½ in proximal to the distal edge of this structure Sometimes a wound severs a nerve just as it branches Several branches then have to be sutured to one stump To manage this, the branches are bundled together by tack stitches in the perineurium to make this bundle correspond to the proximal end The bundle is then sutured to the proximal stump The branches of the median nerve supplying thumb sensation run partly under cover of the muscles of the thenar eminence and may be approached either by an incision along the thenar crease in the palm or, if the wound is more distal in the thumb, by an incision which parallels one of the flexion creases of the thumb or a midlateral incision (Fig 114, Plate 1, *B*)

The medial branches of the *ulnar nerve in the palm* can be approached through an incision made along the midlateral aspect of the palm on the ulnar side, the skin and subcutaneous fat being reflected up in one thickness The nerve will be found lying on the short flexor muscle about ½ in from the edge of the palm The branch of the ulnar to the cleft between the ring and little fingers is best approached through the palm by

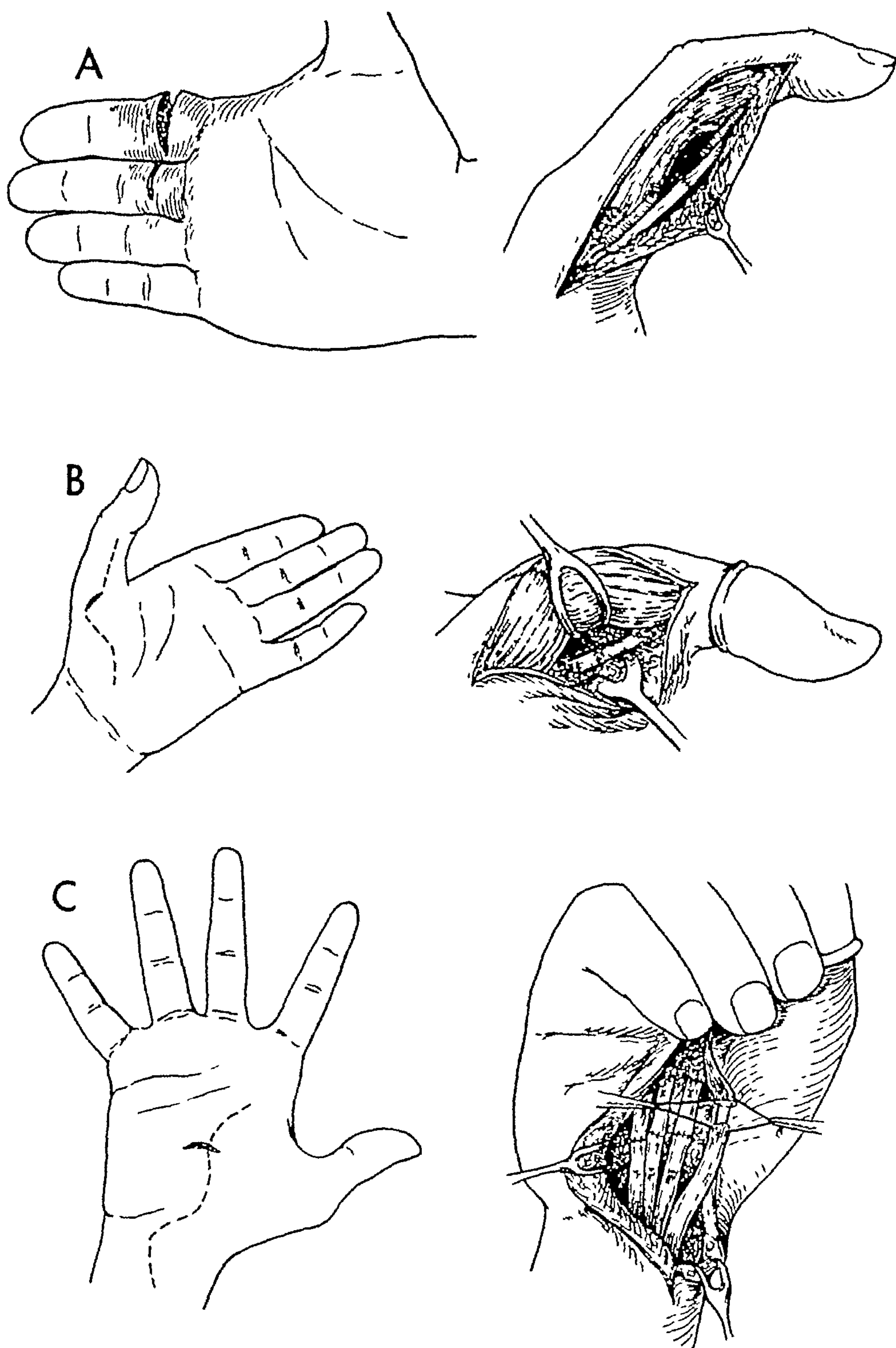


FIG. 114, PLATE 1 —Nerve repair incisions, drawn from photographs of actual cases (see text for technical details) *A*, digital nerve in index finger, *B*, digital branch in thenar eminence, *C*, median nerve and tendons in carpal tunnel

neous fat are raised as a flap, exposing the ulnar nerve and artery and their branches By detaching the origin of the short muscles from the hook of the hamate the motor branch can be followed into the depths of the palm

The division of the ulnar nerve into sensory and motor branches lies adjacent to the crease of the wrist The surgical approach is shown in Figure 114, Plate 2, *A* The sensory branch lies lateral to the motor branch and the ulnar artery The incision should be made along the ulnar border of the palm, jogging across the wrist at the crease and then proximally in the forearm medial to the flexor carpi ulnaris tendon

ON THE BACK OF FINGERS OR THUMB —Nerve damage here is not important There is enough overlap from the nerves on the front or from one side of the finger so that the area of actual anesthesia is not great Furthermore, tactile sensation is not nearly as important on the back as on the front of the hand The dorsal branches of the radial and ulnar nerves may be damaged by lacerations on the back of the wrist, in the snuffbox or just distal to the styloid process of the ulna In these regions the nerve is about 1/16 in in diameter and can easily be picked up and repaired The technic for repair of this nerve is the same as that for repair of the palmar or digital branches

IN WRIST OR FOREARM —Repair of one of the large nerves in the wrist or forearm is more difficult technically than repair of a nerve in the finger because of the many fasciculi present The approach to the nerve should be approximately the same as that described for repair of tendons, the original laceration being prolonged upward and downward at its ends (Figs 114, Plate 1, *C* and 115) Nerves must be distinguished from tendons The nerve is somewhat yellowish or grayish and dull colored compared to the tendon which is dead white and shiny A small vessel runs on the surface of a nerve but not on a tendon Further, the nerve does not move as the wrist or the fingers move The commonest mistakes in the wrist are the suturing of the proximal end of the median nerve to the distal end of the palmaris longus or of the proximal end of the ulnar nerve to the distal stump of the flexor carpi ulnaris This happens because the proximal tendon ends have retracted and are not seen The difficulty can be avoided by working in a bloodless field, making an adequate incision and identifying all structures present

SUTURE TECHNIC —After the nerve ends are identified repair is undertaken (Fig 115, *A–E*), but only after any deeper severed tendons are sutured The nerve should be picked up without trauma, special care being taken to avoid rotation, and the nerve ends matched Usually the cross-

an incision which parallels one of the flexion creases and then turns down along the line of the fourth metacarpal The motor branch of the ulnar nerve is occasionally damaged in the carpal region. Approach is difficult because this branch lies under the main nerve, is surrounded by bony

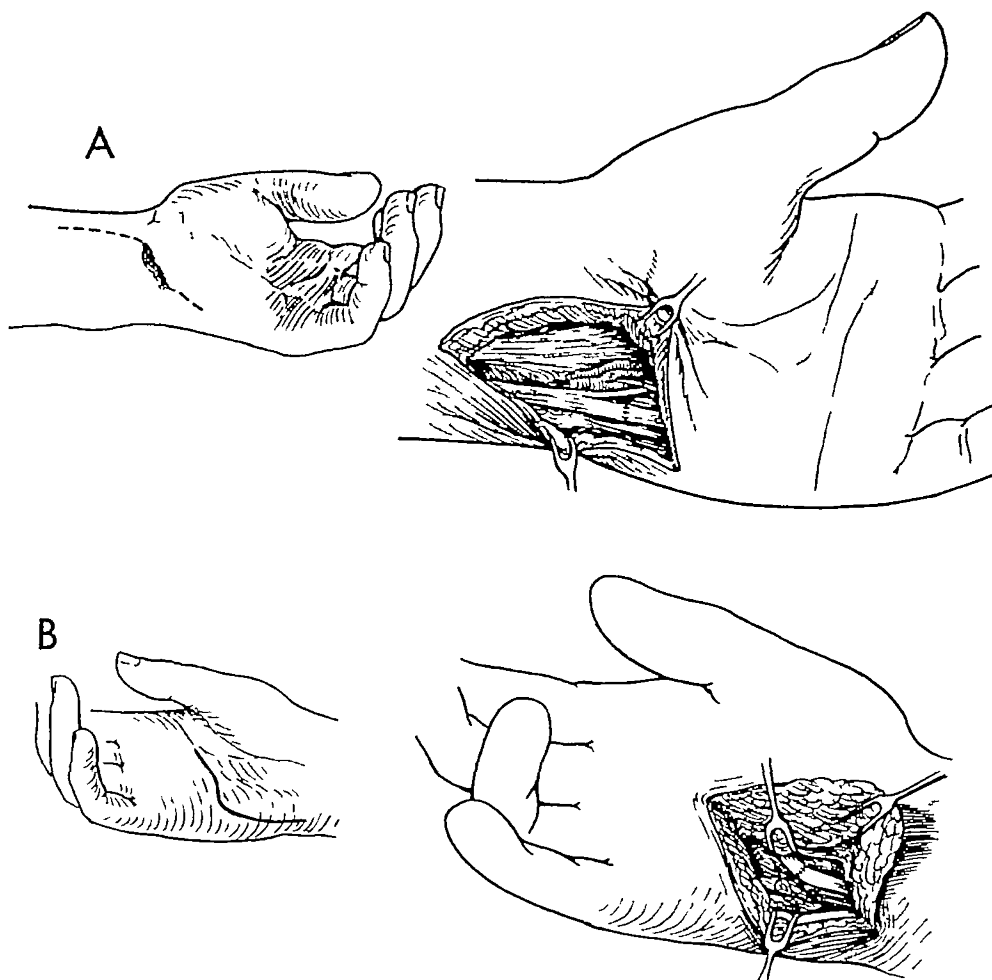


FIG 114, PLATE 2 —Nerve repair incisions *A*, sensory branch of ulnar nerve at wrist crease, *B*, motor branch of ulnar nerve in depth of palm (*B* can be extended proximally into forearm to expose nerve above wrist)

structures and is deeply placed In a fresh laceration a zigzag type of extension is made to approach this nerve

Impromptu incisions made as extensions of a fresh laceration necessarily differ from elective surgical approaches Probably the best general, all-round exposure of the ulnar nerve and its branches in the palm is obtained by an incision along the distal palmar crease across the fourth and fifth metacarpals, then down the ulnar border of the palm in the midlateral line to the wrist (Fig 114, Plate 2, *B*) The skin and subcuta-

be washed away with saline After the nerve is repaired, the bleeding will be controlled by the suture line Suturing of the smaller nerves in palms and fingers may be facilitated by injecting saline or procaine into the ends to make them larger

After suture 1 or 2 cc of normal saline or 1 per cent procaine should be injected with a no 30 needle about 1 cm proximal to the suture line As the solution distends the nerve and flows across into the distal segment it aligns the nerve fibrils and adequacy of the repair is indicated

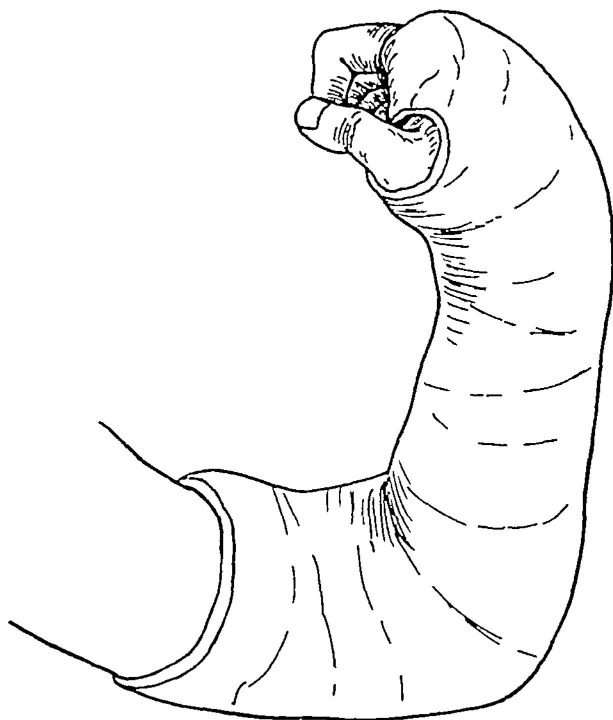


FIG 116—Cast to keep wrist and elbow in position after transplanting ulnar nerve or advancing median nerve

Closure—Before the wound is closed, the position in which the extremity must be held to relax the nerve suture should be ascertained This may require flexion of both the wrist and the elbow for the median or extension of the elbow and flexion of the wrist for the ulnar nerve

As in tendon repairs, it is necessary to have a dry wound and a tensionless closure with nonirritating suture material Both primary and secondary repairs are better if the nerve repair is separated from the skin wound by a small pedicle graft of subcutaneous fascia drawn across the nerve suture before the skin wound is closed This may be tacked in place with a few catgut sutures Bleeding vessels are tied with fine ligatures

section of the nerve is a little elliptical, and the blood vessel on one side aids as a landmark The pattern of the bundles of fibers on the ends will also help in orientation First, two sutures are placed on opposite sides as guides The intervening gap on the front of the nerve is then closed by suturing the nerve ends together, using interrupted sutures of the finest

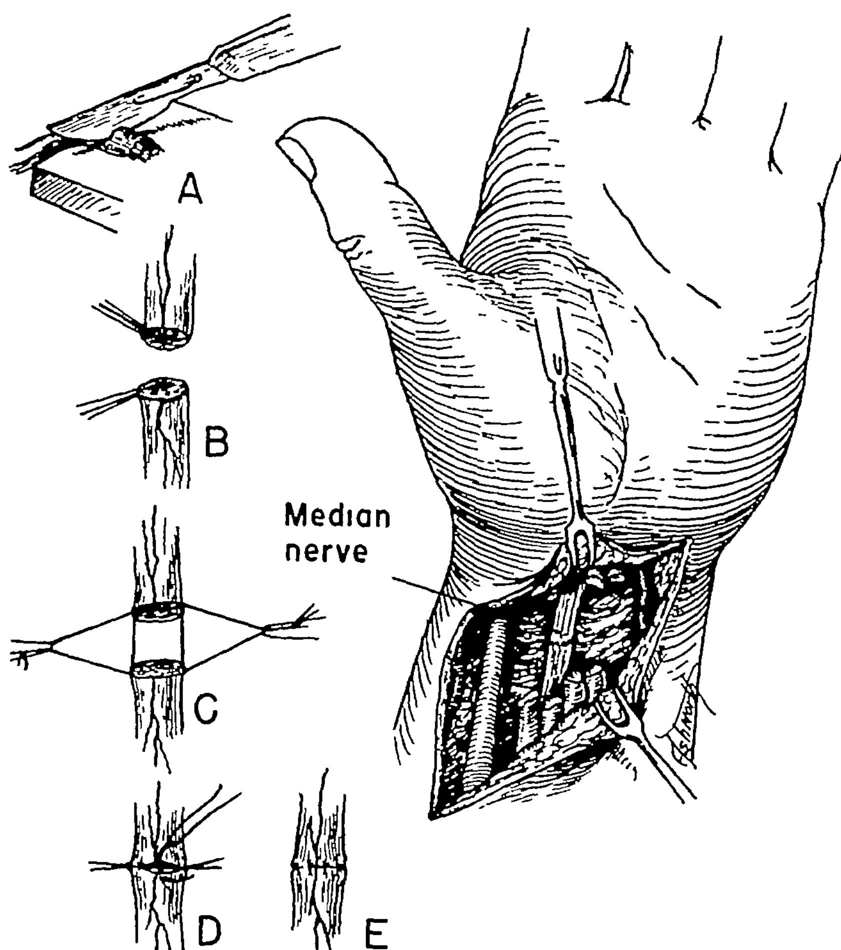


FIG 115 —Technic of nerve repair Operative field shows median nerve repaired at wrist, severed sublimis tendons exposed *A*, regularizing nerve end, *B*, matching nerve ends, *C*, guide sutures placed, *D*, suturing of nerve, *E*, repair properly completed

possible silk which go through the perineurium only Each stitch is carefully knotted and the ends cut as short as possible Using the guide sutures, the nerve can then be turned over and the other side similarly sutured Flexing of the wrist relaxes the nerve so that there is no pull on the suture line during this maneuver Bleeding from the nerve end is usually not much of a problem if a tourniquet is in place Any clot should

the laceration is unsuitable, by using a purely elective type of incision. The nerve is identified by means of the single silk suture left as a landmark during the original wound closure In any dissection to pick up the injured ends of a nerve, it is much easier and better to expose normal nerve proximal and distal to the lesion and then to dissect into the area of the injury Even in a fresh case the nerve ends are frequently separated, and after healing has taken place the ends will usually be found attached to some neighboring structure which makes picking up the nerve at the point of injury difficult It is then necessary to freshen the ends of the nerve and to section back until one is certain that normal nerve has been reached This is best done by laying the nerve on a small piece of wood, such as a suture board, and sectioning it transversely with a new razor

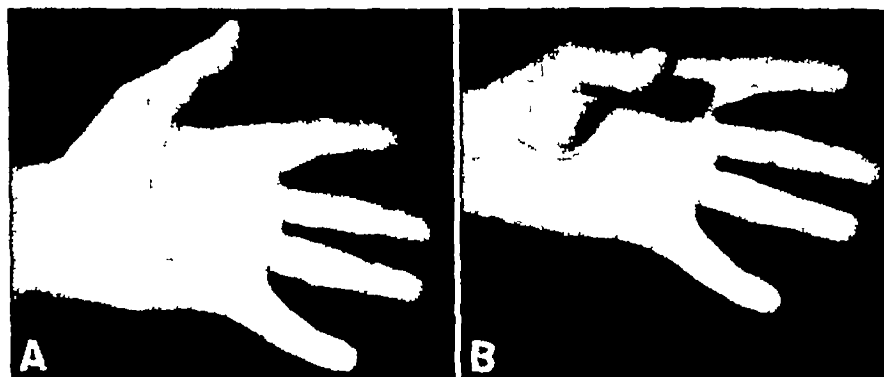


FIG 117—Result of secondary repair of tendons and median nerve in wrist one month after original injury *A* and *B* show ability to oppose thumb, two-point localization, ability to tell sharp from dull, sensation to cotton wisp and some sweating at finger tips present 10 months later

blade, making parallel cuts about 1/16 in apart If a pathologist is available, frozen sections should be made to determine the extent of neuroma Both the proximal and distal ends should be examined

A partial neurorrhaphy may be exceedingly difficult The intact funiculi are dissected out after a longitudinal incision is made in the epineurium for several centimeters on each side of the lesion These are preserved and the damaged funiculi cut back to where the good tissue is encountered An end-to-end neurorrhaphy of these fibers is then accomplished

When the nerve has been avulsed, the damaged segments may show extensive fibrosis and complete degeneration of nerve elements These portions must be excised After the neuroma is excised the gap between the nerve ends must be overcome before suturing is undertaken

BRIDGING THE GAP—This may be done by mobilizing the nerve and

and the skin and subcutaneous tissue closed with a single layer of sutures, preferably interrupted vertical mattress sutures of no 38 stainless steel wire

The extremity is dressed with gentle compression, and plaster splints are applied to hold it in correct position (Fig 116). Drainage is unnecessary unless hemostasis is inadequate, in which case a few small soft-rubber tissue drains may be left in for 24–48 hours The same type of dressing and splinting should be used in the hand, forearm and upper arm In the hand or finger the splint need only be kept in place for a week or 10 days, but in the forearm or upper arm the splinting to relax the suture line must be kept in place for at least a month

When both tendons and nerves are repaired at the wrist the postoperative treatment should also be directed to prevention of permanent flexion contracture of the fingers Usually the patient can accomplish this for himself with intelligent active and passive exercises Occasionally, a traction splint will be necessary to substitute for the paralyzed small muscles of the hand Neither exercises nor traction splints are ever used until healing is complete

Secondary Nerve Repair

If the nerve ends are frayed, the nerve has been avulsed or its blood supply interfered with, or if the condition of the wound is such that primary healing is not expected, the surgeon should make a simple closure of the original wound (p 231) and, if primary healing occurs, do a secondary repair later A better result will then be obtained than if primary repair is made

Secondary suture should never be delayed too long The best results are obtained by repair done within six weeks and the operation should preferably not be postponed longer than two or three months (Fig 117), although a reasonably good repair can be made after as long as six months and occasionally some function has returned after repair done nine months after injury The ability to obtain a good result in secondary nerve repair varies directly with the skill and experience of the operator Even large gaps can be bridged with proper mobilization Short incisions, inexperience, improper handling and inability to carry out a good repair are all factors in failure Perfect wound healing as well as proper splinting and postoperative care is essential

Exposure.—The approach to the nerve may be made either by excising the original laceration and elongating the wound or, if the direction of

the laceration is unsuitable, by using a purely elective type of incision. The nerve is identified by means of the single silk suture left as a landmark during the original wound closure In any dissection to pick up the injured ends of a nerve, it is much easier and better to expose normal nerve proximal and distal to the lesion and then to dissect into the area of the injury Even in a fresh case the nerve ends are frequently separated, and after healing has taken place the ends will usually be found attached to some neighboring structure which makes picking up the nerve at the point of injury difficult It is then necessary to freshen the ends of the nerve and to section back until one is certain that normal nerve has been reached This is best done by laying the nerve on a small piece of wood, such as a suture board, and sectioning it transversely with a new razor

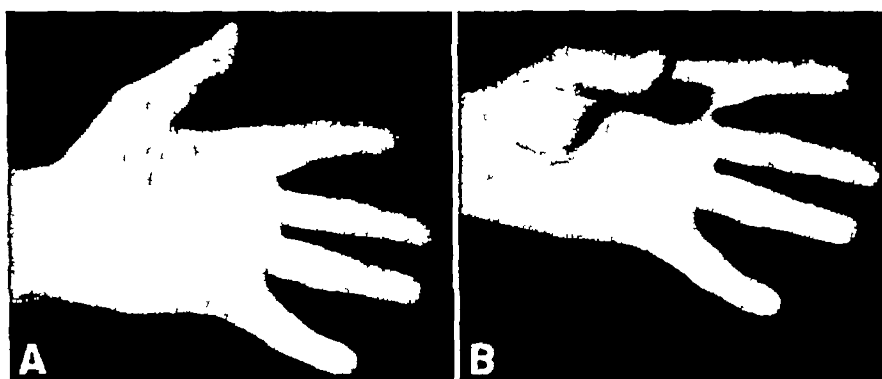


FIG 117—Result of secondary repair of tendons and median nerve in wrist one month after original injury *A* and *B* show ability to oppose thumb, two-point localization, ability to tell sharp from dull, sensation to cotton wisp and some sweating at finger tips present 10 months later

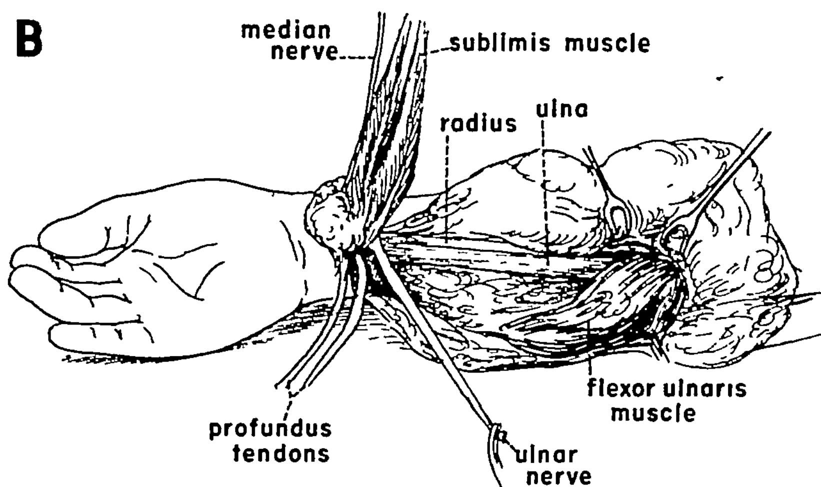
blade, making parallel cuts about 1/16 in apart If a pathologist is available, frozen sections should be made to determine the extent of neuroma Both the proximal and distal ends should be examined

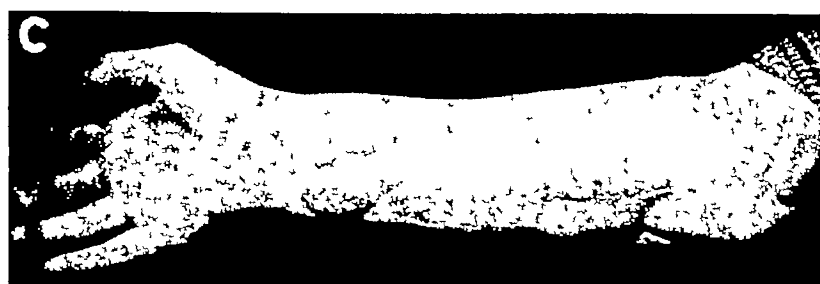
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When the nerve has been avulsed, the damaged segments may show extensive fibrosis and complete degeneration of nerve elements These portions must be excised After the neuroma is excised the gap between the nerve ends must be overcome before suturing is undertaken

BRIDGING THE GAP.—This may be done by mobilizing the nerve and


A


B
median nerve
sublimis muscle
radius
ulna
flexor ulnaris muscle
profundus tendons
ulnar nerve


C


D

FIG 118

flexing adjacent joints In the fingers or palm a gap of ½–¾ in. is overcome by flexing the fingers and the wrist. A gap of 2–3 in. can be overcome by flexing the elbow and drawing the proximal stump of the median nerve distally The ulnar nerve must be transplanted anterior to the elbow before this maneuver can be used on it. This is usually done through a separate 4–6 in incision made over the medial side of the elbow The overlying fascia is severed, and the nerve is picked up in the groove on the trochlea and the muscular branches to the flexor carpi ulnaris and flexor digitorum sublimis are separated and protected After the nerve is freed it is placed subcutaneously in front of the elbow, a very considerable gap can then be overcome by flexing the elbow A more radical procedure consists of transplanting the entire nerve subcutaneously to the front of the elbow (Fig 118).

To transplant the median nerve subcutaneously to bridge large gaps, a series of incisions is made in the forearm and arm and the main bundle of the median nerve separated from the muscular branches as far up as the lower biceps region, preserving the muscular branches as they occur. The nerve is then brought down subcutaneously anterior to the lacertus fibrosus and the elbow flexed acutely

SUTURE TECHNIC —The all important matter in any secondary repair is that there should be absolutely no tension on the suture line The same suture technic is used as in primary repairs, with the same wound closure, dressings and splints A somewhat longer period of splinting in flexion, ranging from five to six weeks, is necessary if a large gap has been bridged. After the splint is removed, the patient is instructed to extend the arm in a gradual fashion over a period of several weeks

EXPOSURE OF NERVES IN UPPER ARM AND FOREARM —In the upper arm the *median and ulnar nerves* are exposed by an incision which begins over the tendons of the pectoralis major and curves into the natural folds of the axilla The incision runs down the medial aspect of the upper arm

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← FIG 118 —*A,* arm injured in hay baler *B,* diagram of injured structures median and ulnar nerves and all flexor tendons except profundus of index finger and long flexor of thumb were avulsed In original repair, avulsed muscles were excised and profundus tendons transferred to index finger muscle, wrist flexors tenodesed, median and ulnar nerves replaced using single black silk suture, wound closed and secondary abdominal flap At nerve repair 2½ months later, distal nerve ends were found completely degenerated from a distance of about 4 in Entire ulnar nerve and all median nerves except motor branches to remaining muscle were transplanted subcutaneously to front of elbow, mobilizing them all the way up the arm and forearm, and gap was overcome by flexing wrist and elbow acutely *C* and *D,* end result hand has good grip and pinch and light touch sensation at finger tips Patient identifies objects placed in hand (From Nichols Am J Surg 83 364-371, 1952)

and at the elbow curves behind the medial epicondyle In the forearm this incision is extended down the ulnar side of the volar aspect for a short distance and then turned medially for the median nerve or kept on the ulnar side of the arm for the ulnar nerve (Figs 119 and 120) The muscular branches of the *ulnar nerve* arise in the groove on the olecranon. By disconnecting the flexor carpi ulnaris from its origin on the condyle of the humerus one can follow the ulnar nerve through the tunnel in this muscle and into the space between the flexor carpi ulnaris and flexor pro-

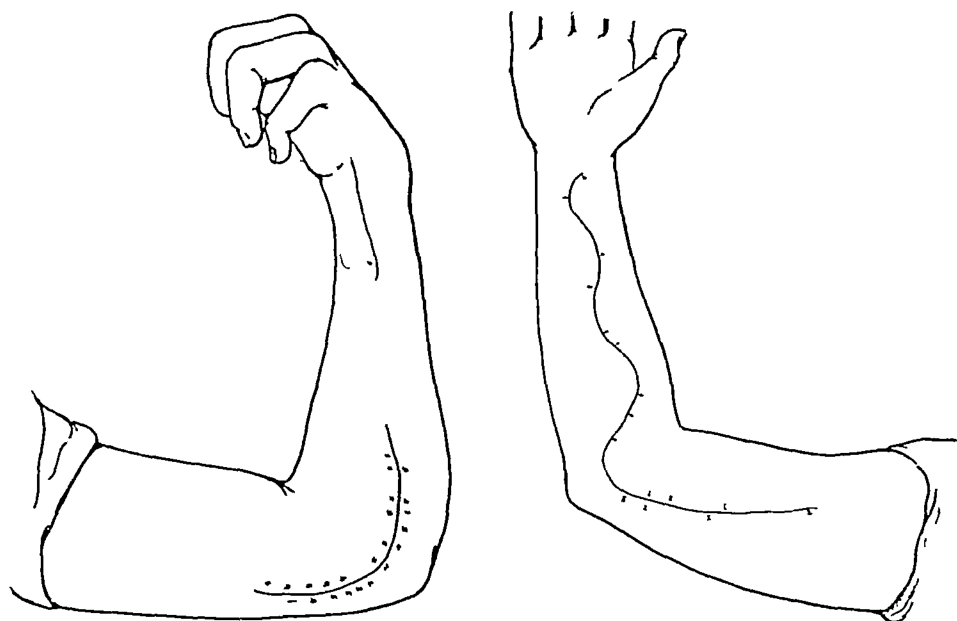


FIG 119 *(left)* —Incisions to transplant ulnar nerve at elbow when there is a wide gap at the wrist.
FIG 120 *(right)* —Incision to expose median nerve in upper arm and forearm

fundus muscles in the forearm A straight incision following the flexor carpi ulnaris tendon will uncover the nerve in the forearm

The *median nerve* incision, after leaving the medial epicondyle, turns toward the middle of the volar surface of the forearm and thence continues as a serpentine down the forearm By incision of the fibers of the lacertus fibrosus the nerve is uncovered at the elbow and can be followed through the pronator teres, which separates it from the flexor carpi radialis, into the space between the deep and superficial muscles of the forearm The nerve can then be exposed at the wrist and traced upward, retracting the flexor carpi radialis laterally, the flexor digitorum sublimis medially and the pronator teres upward

Exposure of the *radial nerve* in the upper arm is best done by an incision down the inside of the arm, the neurovascular bundle being exposed between the triceps posteriorly and the biceps, brachialis and coracobrachialis anteriorly The nerve is then traced to a point where it winds around the humerus Posteriorly and laterally in the lower third, the nerve is exposed by an incision which begins along the posterior border of the deltoid and extends between the deltoid and the long head of the triceps down to the medial aspect of the brachioradialis at the elbow The incision then crosses the belly of the brachioradialis and the extensor carpi radialis longus This incision can be carried down the dorsum of the forearm along the radial side of the extensor digitorum communis

The nerve divides into deep and superficial branches at the elbow It can be picked up just lateral to the biceps tendon and followed under the brachioradialis muscle belly into the planes between the fibers of the supinator Distal to the supinator an incision between the extensor carpi radialis longus and the extensor digitorum communis will uncover the nerve in the forearm and it can be traced back toward the supinator The supinator can be divided at right angles to its fibers

Occasionally, after injuries from operative procedures on a fractured humerus, large gaps in the radial nerve must be overcome I have transplanted the nerve anterior to the humerus, preserving the branches to the triceps muscle by stripping them up, then bringing the nerve beneath the biceps toward the distal end in the brachioradialis muscle

and at the elbow curves behind the medial epicondyle In the forearm this incision is extended down the ulnar side of the volar aspect for a short distance and then turned medially for the median nerve or kept on the ulnar side of the arm for the ulnar nerve (Figs 119 and 120) The muscular branches of the *ulnar nerve* arise in the groove on the olecranon By disconnecting the flexor carpi ulnaris from its origin on the condyle of the humerus one can follow the ulnar nerve through the tunnel in this muscle and into the space between the flexor carpi ulnaris and flexor pro-

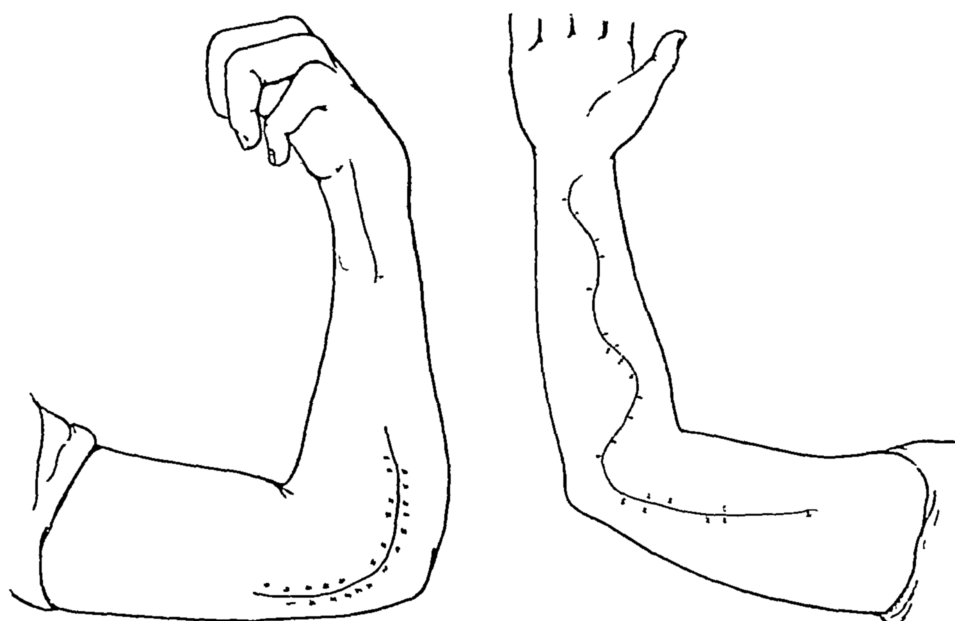


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lar margin with posterior and upper displacement of the distal fragment This fracture is quite rare, most of the compression and extension fractures being only 1 or 2 cm from the distal margin Several other names are applied to other fractures in this region Smith's fracture is a reverse Colles fracture and Barton's fracture is a fracture of the dorsal lip of the distal end of the radius

PATHOLOGY—*Incomplete fractures*—These are common in children There are buckling of the posterior cortex and a slight backward bending of the lower end of the bone, accompanied at times by a similar deformity in the lower end of the shaft of the ulna In adults a fracture caused by direct violence occasionally results in a fissure across the distal end of the radius extending into the joint Such fractures are easily overlooked

Complete fractures—Complete fractures with displacement are more common than either of the preceding types The distal segment is frequently comminuted and the fracture line may run transversely or may slope backward, backward and laterally, or medially The articular surface may be partly damaged by fractures extending into the joint The silver fork deformity described in all textbooks is due to the upward tilting of the distal articular surface of the radius and to the dorsal displacement of the distal fragments There is a certain amount of supination of the distal fragment, so that the hand is rotated outward on the shaft Impaction of the distal fragment on the broken ends of the shaft is usually present because the lower end is broader than the shaft and its soft cancellous bone becomes impaled on the firm cortical bone of the shaft In the more extensive types of fracture, and especially in older persons, so much comminution of this soft cancellous bone occurs that frequently there is a real loss of bone substance Sometimes this results in the end of the radius being driven directly into the shaft without being tilted backward It is usual for the styloid process of the ulna to be torn off, and the triangular fibrocartilage is torn or displaced as the distal end of the radius moves backward in relation to the head of the ulna

Except for the styloid process, the lower end of the shaft of the ulna and the head of the ulna are usually not broken The distal radioulnar joint may be considerably disrupted, and this is one reason that rotation of the wrist is so commonly painful after this type of fracture Considerable bloody extravasation and swelling are present in addition to bone deformity In the most severe fractures the median nerve is impinged on by the sharp spike of the radial shaft and compounding of the fracture may occur, the radial shaft being driven through the skin on the front of the wrist

CHAPTER ELEVEN

Fractures and Dislocations

FRACTURES OF DISTAL END OF RADIUS

Colles' Fracture

COLLES' FRACTURES are equal in frequency to fractures of the collar bone and are exceeded only by fractures of ribs and fingers Most Colles' fractures are caused by falls on the outstretched hand, but the forces which produce the fracture vary from case to case Usually the hand is pronated and the wrist extended with the muscles tensed When the hand strikes the ground the heel of the palm receives the blow, which is transmitted through the carpal bones to the lower end of the radius, pushing it backward Depending on the inclination of the arm in relation to the ground, there may be hyperextension of the wrist as well as a shearing action and a certain amount of torsion as the muscles forcibly pronate the forearm at the moment of impact The type of fracture depends on the direction and amount of force applied and varies from a simple impaction with perhaps no displacement to complete separation of the fragments and even at times compounding through the skin on the anterior and posterior surfaces These fractures may be incomplete or complete and with or without displacement There may also be fractures involving the lower end of the radius and ulna which are caused by direct violence These, as well as epiphyseal separations in children, are grouped together because the region affected and the general principles of treatment are the same

By common usage, most compression and extension fractures of the lower end of the radius are called Colles' fractures although the lesion described by Colles was a transverse fracture about 4 cm above the articu-

in a plaster cast for three to four weeks, some ulnar deviation helps to prevent shortening during the process of healing The cast should extend from the upper part of the forearm to the transverse flexion crease of the palm During convalescence the patient should be made to move the fingers and the shoulder The disability produced by immobilizing the fingers in the cast or by keeping the arm tied down in a sling is worse than that resulting from no treatment at all

REDUCTION —*Anesthesia*—In most fractures of the lower end of the radius, anesthesia will be required for reduction Whether general or local



FIG 121—*A*, simple Colles' fracture, *B*, following proper reduction This fracture may be overlooked without x-rays

anesthesia is used rests largely with the individual operator Local anesthesia, although safer in some instances in which general anesthesia is contraindicated, requires a certain amount of skill on the part of the surgeon and co-operation on the part of the patient

Local anesthesia is more satisfactory when a fracture is seen early, because after 24 hours the extravasated blood will have coagulated It is necessary that the tissues around the radius be completely infiltrated, and it is preferable that an additional injection be made into the hematoma between the fracture ends After the procaine is deposited around the fracture site, the needle can usually be slipped between the bone ends

In children an epiphyseal separation results from a fall in exactly the same way that a Colles' fracture occurs in an adult The epiphysis may be simply loosened, may be partially displaced backward or may be completely separated and accompanied by a fracture of the posterior portion of the shaft

Whenever the fracture line involves the articulating surfaces there is apt to be some permanent disability even though little or no displacement is present Oblique fractures through the radial styloid fall into this classification At times only the posterior articular lip of the radius is torn off, and the carpal bones are dislocated posteriorly

SIGNS AND SYMPTOMS —A certain amount of swelling and tenderness over the lower end of the radius and pain on use of the hand are common to all these fractures When displacement is present, the silver-fork deformity may be obvious If this is not present, some change of relationship between the radial and ulnar styloids can often be detected Careful palpation of the posterior surface of the radius should always be done, by this means, points of tenderness may be picked up even in incomplete fractures In the more severe fractures, inspection will reveal some radial deviation of the hand, broadening of the wrist and absence of the prominence of the head of the ulna As the distal fragment of the radius moves dorsally, it carries the hand with it This gives rise to the abrupt dorsal prominence over the fracture site In all these fractures, whether displacement is present or not, there is loss of supination of the wrist Use of the fingers is lost to a variable degree, depending on the age of the patient and the extent of displacement Epiphyseal separations produce symptoms exactly like those of a fracture

TREATMENT —In any suspected fracture of the wrist the physician has an obligation to make an absolutely certain diagnosis Hence, x-rays should be taken of any so-called sprained wrist. Even though no displacement is present, when a fracture line exists it is necessary to immobilize the wrist until healing has taken place When there is slight displacement (Fig 121), this should always be corrected because the deformity tends to become exaggerated during healing Although patients with old, healed fractures of the lower end of the radius with considerable deformity but few complaints are commonly seen, one will find on examination that some weakness and limitation of motion and more or less pain are actually present and that there were months or years of discomfort before the patient was able to accommodate himself to the presence of the deformity

If the fracture fragments are not out of position, immobilization is all that is necessary. The wrist is placed in a neutral or slightly flexed position

in a plaster cast for three to four weeks, some ulnar deviation helps to prevent shortening during the process of healing The cast should extend from the upper part of the forearm to the transverse flexion crease of the palm During convalescence the patient should be made to move the fingers and the shoulder The disability produced by immobilizing the fingers in the cast or by keeping the arm tied down in a sling is worse than that resulting from no treatment at all

REDUCTION —*Anesthesia*—In most fractures of the lower end of the radius, anesthesia will be required for reduction Whether general or local

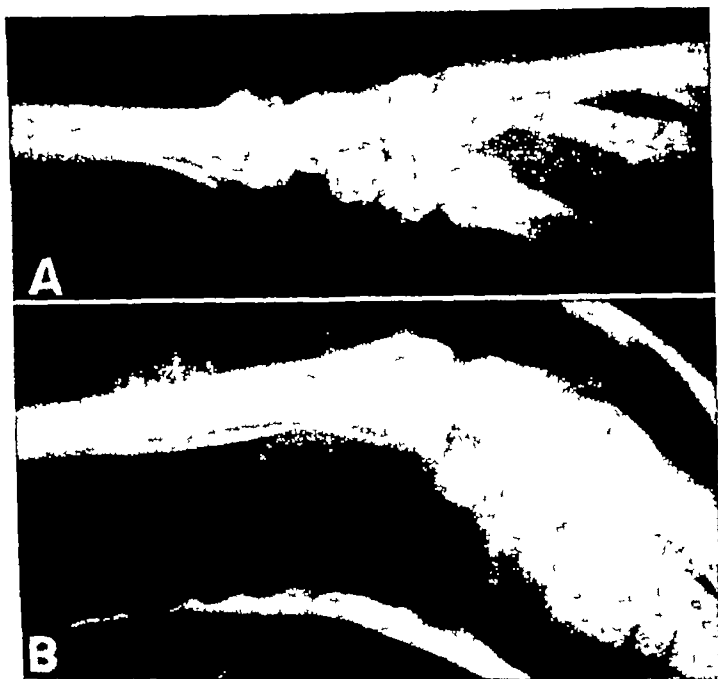


FIG 121 —*A*, simple Colles' fracture, *B*, following proper reduction This fracture may be overlooked without x-rays

anesthesia is used rests largely with the individual operator Local anesthesia, although safer in some instances in which general anesthesia is contraindicated, requires a certain amount of skill on the part of the surgeon and co-operation on the part of the patient

Local anesthesia is more satisfactory when a fracture is seen early, because after 24 hours the extravasated blood will have coagulated It is necessary that the tissues around the radius be completely infiltrated, and it is preferable that an additional injection be made into the hematoma between the fracture ends After the procaine is deposited around the fracture site, the needle can usually be slipped between the bone ends

where, on aspiration, blood will be encountered About 20 cc of procaine injected here will give excellent anesthesia, and muscle spasm will be overcome when pain is eliminated Occasionally cases are reported in which infection resulted, probably from careless technic. If the skin and the anesthetic solution are properly prepared and the surgeon takes the usual precautions of wearing mask and gloves, the danger of infection is slight

If general anesthesia is elected, the anesthetist should be aware of the danger of explosion when the fluoroscope is used or when the lights are turned off and on and should be able to carry the patient on anesthesia in the darkened room if necessary

Technic.—The general principles in reduction of Colles' fracture are to disimpact the fracture, to replace the bone fragments in normal end-to-end position, at the same time restoring the volar angulation of the distal radial articulating surface, and to restore length to the radius Any rotation of fragments must also be corrected

There are two methods of approaching the problem of reduction In one, the force applied is largely leverage accompanied by traction This method was for years considered the only method of reducing these fractures The wrist is first strongly hyperextended, loosening the impaction (Fig 122, *A*), and is then strongly flexed with traction and ulnar deviation to bring the distal fragment back into normal position (Fig 122, *B*). The surgeon grasps the lower end of the proximal radial fragment as near the fracture site as he can with one hand and the distal radial fragment and adjacent carpal region with the other hand and uses his thumbs on the dorsum of the fractured bones to help manipulate them into position (Fig 122, *C*) Considerable force may be necessary to break up the impaction, after this is accomplished the hand should immediately be swept toward the flexed position, at the same time using strong traction, ulnar deviation and pronation and manipulating the bones into place with the thumbs When reduction has been properly carried out, the hand will drop into 90 degree flexion without resistance (Fig 122, *D*)

A second method which has many adherents depends on traction rather than leverage, although the fundamental maneuver does not differ greatly The proximal fragments are either held by an assistant or fastened to the bed or stretcher by a strap at the elbow With the elbow flexed, the surgeon makes strong traction on the hand, grasping the wrist and lower fracture fragment with both hands When the fragments have been disimpacted and pulled apart, reduction is accomplished by pronating the adducted hand and, in addition, by making pressure over the distal frac-

ture fragment and flexing the wrist, meanwhile maintaining ulnar deviation It is claimed that the wrist may be put up in considerably less flexion with this method than with the leverage method and that there is less shortening of the radius

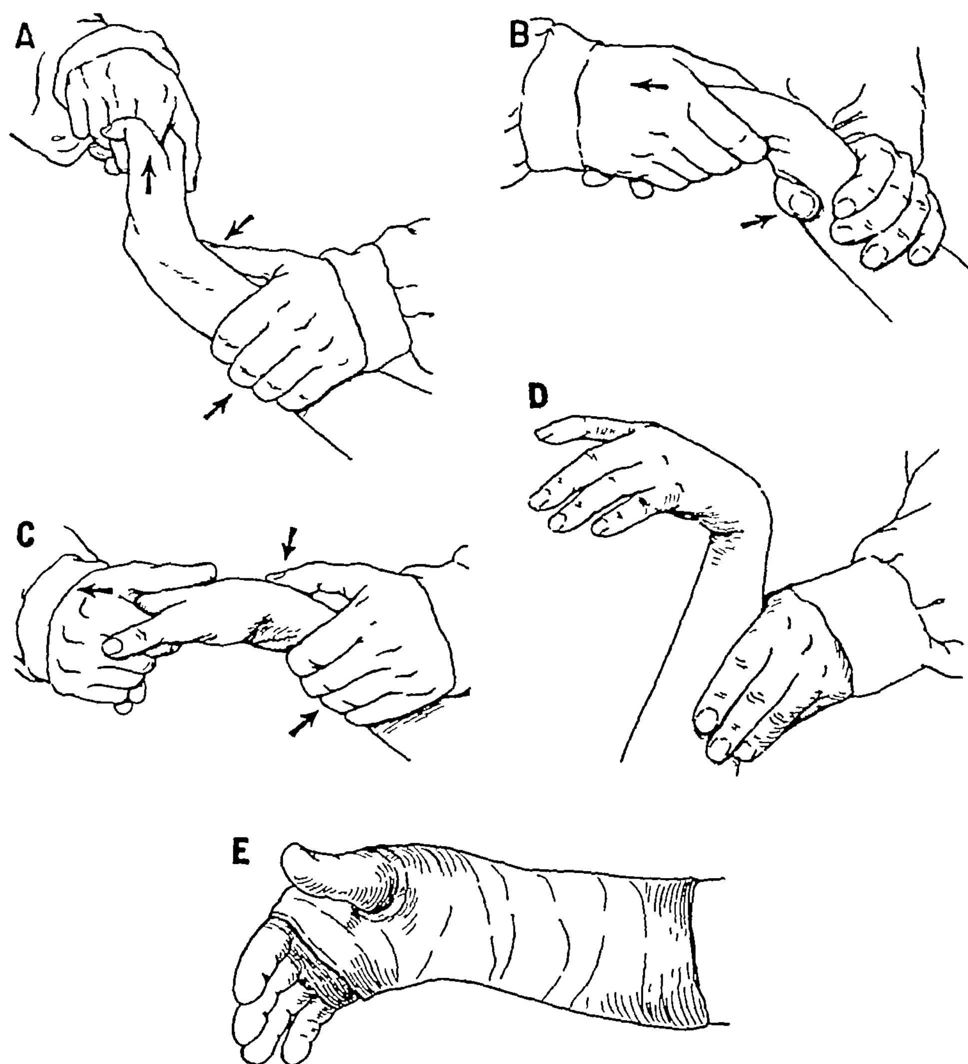


FIG 122—Reduction of Colles' fracture *A*, breaking up impaction by extending wrist, *B*, reduction using traction, ulnar deviation and flexion, *C*, distal radial fragment pressed down into place, *D*, test of reduction, and *E*, cast applied

One can often determine whether or not reduction is satisfactory without the use of x-rays When the deformity is reduced, the styloid process of the radius will be distal to the styloid of the ulna and the fracture deformity can no longer be palpated on the dorsal surface The dorsal prominence of the ulna will have disappeared and the wrist can be nor-

mally flexed In severely comminuted fractures (Fig 123), the bone displacement, especially the dorsal angulation of the distal fragment, tends to recur as soon as flexion is released Momentary examination with a fluoroscope will indicate what position is necessary to maintain reduction Many authorities object to use of the fluoroscope, and the author wishes to emphasize that it should be used only to check position of fragments

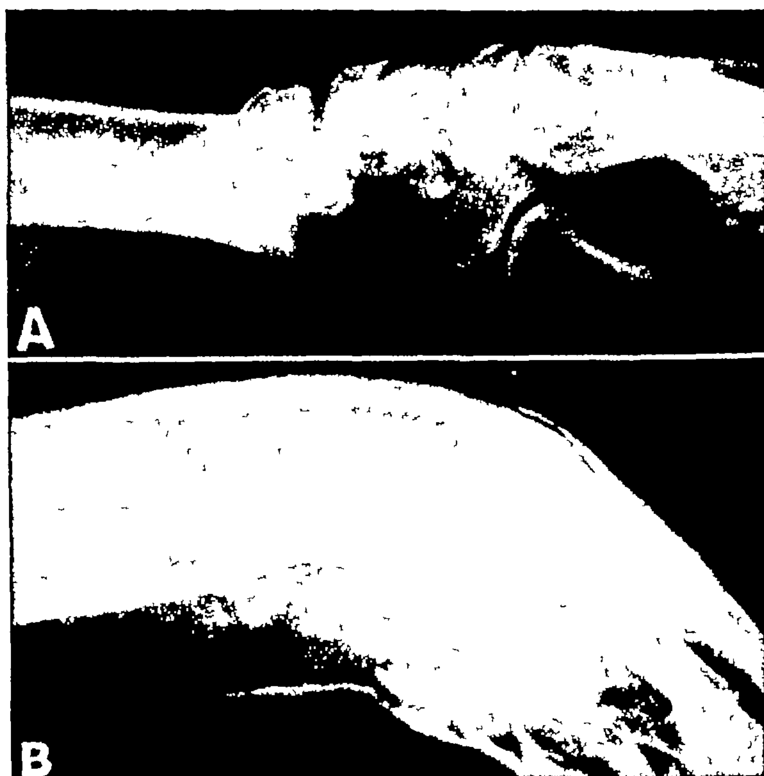


FIG 123 —*A*, moderately severe Colles' fracture, *B*, after fairly good reduction

after reduction A cone is used to show the fracture site and the operator's hands are kept out of the beam of radiation

The arm is held with the elbow extended and the wrist is first examined anteroposteriorly to determine whether the length of the radius has been restored The arm is then rotated at the shoulder and the lateral view of the wrist inspected to determine how much flexion at the wrist is necessary to maintain the normal volar angle of the distal radial articulating surface Once this position is ascertained the surgeon should not change the position of the arm but should hold the bones in alignment and have an assistant apply a snug-fitting plaster cast (Fig 122, *E*).

Immobilization —For the average surgeon the best method of applying

plaster is to use snug-fitting plaster splints over a minimal amount of sheet wadding The sheet wadding is wound on like a spiral bandage, starting at the elbow and overlapping each turn about half way with one additional layer around the wrist With too much padding the extremity will tend to loosen in the cast and the fracture will tend to become displaced If no padding is used, considerable skill is necessary to avoid a cast that is too tight and to avoid pressure sores over bony prominences Plaster splints are applied over the sheet wadding, three or four splints of two or three thicknesses each being used over the dorsum and a similar number over the volar surface. A thin layer of circular plaster or gauze will hold the splints in place While the plaster dries the wrist is held in the position which maintained reduction Before it has set completely the cast should be trimmed away from the hand so that the metacarpophalangeal joints can be flexed to 90 degrees, and from the thumb so that it can be opposed to the fingers

In severely comminuted fractures and in fractures in which it is difficult to maintain reduction it is advantageous to immobilize the elbow (the forearm is kept pronated), extending the cast to the middle of the upper arm After three weeks, this cast is removed and replaced with a short forearm cast

In fractures difficult to maintain in reduction cast application may be simplified by placing the patient's elbow on the table and holding the arm vertical, with the hand in the position that maintains reduction A plaster splint of appropriate thickness with a thin layer of sheet wadding is then applied to the dorsum of the forearm and wrist and molded to fit This is allowed to dry for a few moments, being held meanwhile by a circular gauze bandage When it is almost dry another thin layer of sheet wadding is applied and the cast is completed as a circular cast, incorporating the elbow, forearm and hand to the distal crease This cast should be split to the skin along the ulnar border of the forearm and hand

A great many proprietary splints and simple wooden splints can be used to maintain reduction of Colles' fractures Although there is no objection to their use by one who understands the principles of reducing a fracture and maintaining reduction, these splints will often be inadequate since each fracture presents an individual problem and the angle which will maintain one fracture in reduction may not be at all successful for another

OPEN FRACTURES *—In badly comminuted or open fractures of the lower end of the radius, the method of reduction and fixation described

* "Open" fracture is now the term preferred for "compound" fracture

mally flexed. In severely comminuted fractures (Fig. 123), the bone displacement, especially the dorsal angulation of the distal fragment, tends to recur as soon as flexion is released Momentary examination with a fluoroscope will indicate what position is necessary to maintain reduction Many authorities object to use of the fluoroscope, and the author wishes to emphasize that it should be used only to check position of fragments

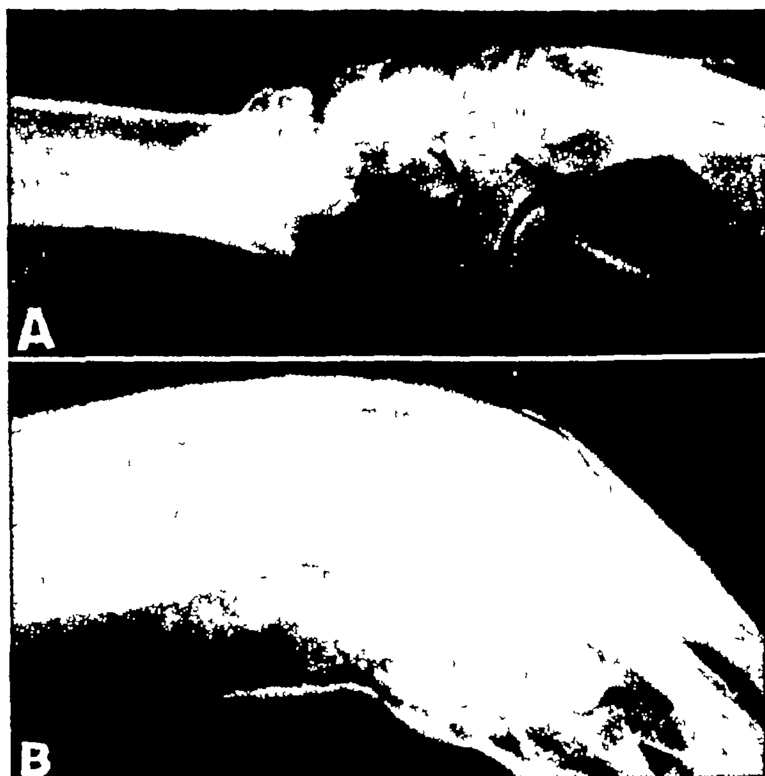


FIG 123 —*A*, moderately severe Colles' fracture, *B*, after fairly good reduction

after reduction A cone is used to show the fracture site and the operator's hands are kept out of the beam of radiation

The arm is held with the elbow extended and the wrist is first examined anteroposteriorly to determine whether the length of the radius has been restored The arm is then rotated at the shoulder and the lateral view of the wrist inspected to determine how much flexion at the wrist is necessary to maintain the normal volar angle of the distal radial articulating surface Once this position is ascertained the surgeon should not change the position of the arm but should hold the bones in alignment and have an assistant apply a snug-fitting plaster cast (Fig 122, *E*).

Immobilization —For the average surgeon the best method of applying

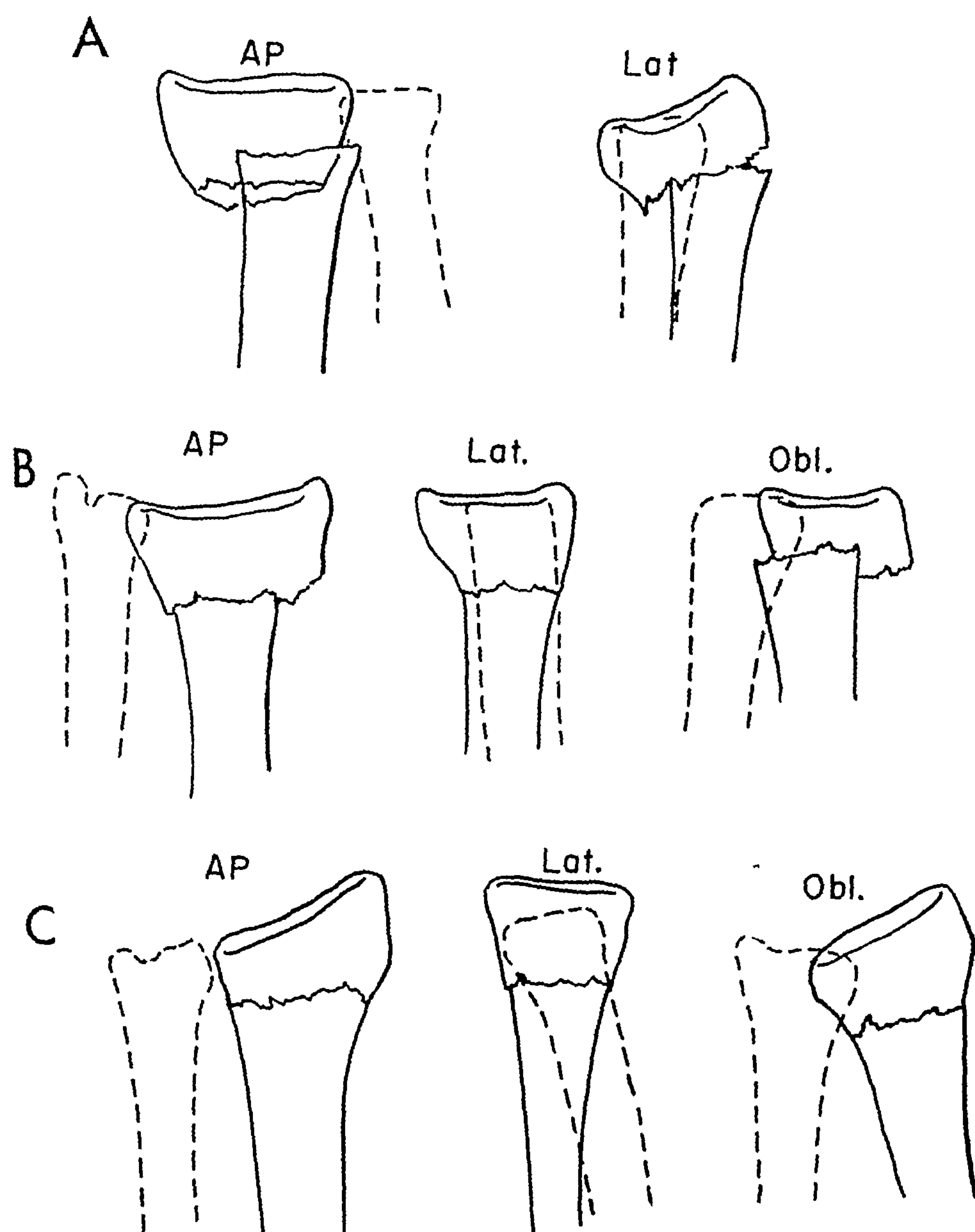


FIG 125 —Anteroposterior, lateral and oblique views of Colles' fracture (drawn from actual case) *A*, original, *B*, after manipulation and apparent reduction, *C*, after true reduction

faces downward about 15 degrees, that the length of the radius is restored and that the inferior radioulnar relationship is normal. True anteroposterior, lateral and *oblique* x-ray views are very important after reduction of some Colles' fractures The oblique view will often show failure of reduction, even when anteroposterior and lateral views shown an apparently acceptable result Figure 125 illustrates such a case X-rays should also

may be quite inadequate In these fractures some form of continuous traction may be necessary to prevent marked shortening and angulation of the lower radial fragment A simple method is to drill a Kirschner wire through the metacarpal of the thumb or through the second and third metacarpals and to attach the wire to an outrigger on the cast by rubber bands so that continuous traction is made in the axis of the radius Instead

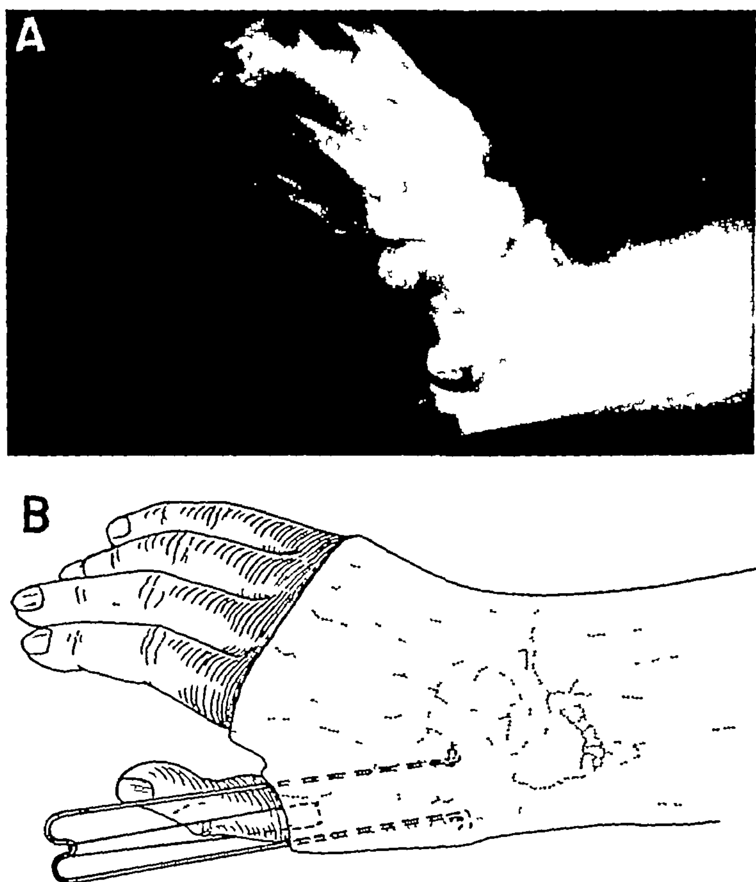


FIG 124 —*A*, severe open Colles' fracture *B*, traction on thumb metacarpal used to maintain reduction (diagram drawn from x-rays)

of the Kirschner wire a loop of 24 gauge stainless steel wire may be passed through a drill hole placed in the first metacarpal and used for traction When this method is used, the same principles of reduction apply and the dorsal displacement, angulation and rotation of the distal fragment must still be corrected The traction simply prevents shortening and recompounding of the fracture (Fig 124)

POSTREDUCTION CARE —Routine postreduction x-rays should be taken and studied to make sure that the distal articulating surface of the radius

from the displaced distal fragment The head of the ulna is prominent on the dorsum

TREATMENT —If there is little or no displacement, the wrist should be immobilized by splints or a cast in a slightly cocked-up position for about four weeks In fractures with displacement reduction should be carried out under anesthesia The fragments must be pulled apart and the lower fragment then pushed backward into place on the end of the shaft Ulnar deviation is used to overcome the shortening, and dorsiflexion to correct the volar angulation of the distal fragment When the fracture is



FIG 126 —*A*, reverse Colles' fracture *B*, after manipulative reduction and immobilization in extension and ulnar deviation.

properly reduced, complete dorsiflexion of the wrist can be obtained without resistance The hand then is immobilized in a neutral position as regards flexion and extension with ulnar deviation If this is not adequate to maintain position, the forearm is supinated and the hand dorsiflexed and ulnar deviated Because of the strong pull of the flexor tendons there is a tendency for these fractures to become displaced even in the cast, and a certain amount of residual deformity is often present after healing For this reason traction similar to that shown in Figure 121 may be necessary, and the patient must be followed more carefully than after the usual type of Colles' fracture

be taken after a week or 10 days to detect any redisplacement If redisplacement is even slightly suggested it should be corrected and a new cast applied If the position of the fragments is satisfactory and the cast is still snug, the cast is left on until the end of four or six weeks If a position of extreme palmar flexion has been necessary to maintain reduction, it is advisable to change the cast and "let up" on the extreme position after two weeks so that the fingers can be better exercised Sometimes the cast loosens and the fracture slips, necessitating a new cast and additional flexion at the wrist Anesthesia is seldom necessary for this maneuver The patient must be required to exercise his fingers continually throughout convalescence

The patient should be watched during the first day after reduction to make sure that the cast is not too tight After a few days, the patient should be encouraged to discard the sling and exercise the shoulder and the fingers Overenthusiastic use of the hand is not recommended One of my patients redisplaced the fracture on the tenth day by forcibly pushing on a can opener X-rays of the wrist are taken at the end of four or five weeks to ascertain the amount of callus and healing, a more accurate estimate will be obtained if the cast is removed before x-rays are taken If insufficient callus is present, as is often the case in older persons or in fractures with marked comminution or dislocation of the lower end of the ulna, it may be necessary to maintain the hand in plaster for six or seven weeks

Smith's Fracture

Smith's fractures, or reverse Colles' fractures, are caused by a fall with the wrist flexed, the dorsum of the hand striking the ground A blow across the dorsum of the hand may also produce this type of fracture The displacement is just the opposite of that in the common extension type of fracture, the fracture line taking an oblique course through the lower cancellous portion of the radius The displaced fracture is usually a triangular block of bone, the base of the triangle including the anterior surface of the radius (Fig 126) The lower fragment is frequently comminuted If the distal radioulnar joint is involved, the ulnar styloid may be broken

The classic deformity has been called the gardener's spade deformity The distal end of the forearm is angulated toward the palm of the hand and the whole hand is carried forward, the distal end of the upper fragment is prominent on the dorsum and the wrist is prominent anteriorly

from the displaced distal fragment The head of the ulna is prominent on the dorsum

TREATMENT—If there is little or no displacement, the wrist should be immobilized by splints or a cast in a slightly cocked-up position for about four weeks In fractures with displacement reduction should be carried out under anesthesia The fragments must be pulled apart and the lower fragment then pushed backward into place on the end of the shaft. Ulnar deviation is used to overcome the shortening, and dorsiflexion to correct the volar angulation of the distal fragment When the fracture is



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BARTON'S FRACTURE

This is a fracture of the posterior articulating margin of the lower end of the radius It is a fracture-dislocation in which the carpals are dislocated posteriorly and the joint margin is fractured

The cause of this fracture is probably closely related to that of the more usual Colles' fracture, but the forces are such that only a small portion of the posterior articulating lip of the radius is torn off Frequently there is little displacement of the detached fragment However, if this fracture is neglected, there will be a tendency to subluxation at the radiocarpal joint, and the damage to the distal articulating surface of the radius will result in impaired function of the wrist

TREATMENT—Under anesthesia, the displaced fragment is pressed back into position and at the same time the hand is dorsiflexed to prevent the proximal row of carpal bones from again becoming subluxated A snug-fitting plaster cast should be applied and the position maintained for three weeks to a month

FRACTURE OF THE RADIAL STYLOID

A direct blow over the wrist is the usual cause of this fracture, although it may be produced by a fall which directs the force toward the radial side of the wrist In most cases not much displacement is indicated on x-rays, but there is considerably more damage to the articulating surface than would be apparent so that some residual soreness and disability frequently follow healing

TREATMENT—Any displacement must be corrected as accurately as possible, the usual maneuver to reduce the displacement being ulnar deviation of the hand and direct pressure over the distal fragment. The forearm and hand should then be immobilized in a snug-fitting plaster cast which incorporates the palm but leaves the fingers free A position midway between pronation and supination is usually used and the hand is held in adduction (ulnar deviation) There being no involvement of the inferior radioulnar joint in these fractures, it is not necessary to immobilize the elbow The cast should be left on for three weeks to a month and active exercises then instituted Occasionally immobilization for two to three months is necessary to obtain union

EPIPHYSEAL SEPARATION AT LOWER END OF RADIUS

A fall of the same type as that which causes Colles' fracture in adults will displace the epiphysis in children in whom the epiphysis at the lower

end of the radius is not closed The displacement runs through the epiphyseal line, and the metaphysis is almost always displaced dorsally on the distal end of the diaphysis The lower fragment may be simply loosened or may be completely displaced Frequently there is an associated fracture of the lower end of the shaft of the diaphysis, a fragment of bone from the dorsal lip being carried backward with the epiphyseal plate

TREATMENT —The problem of reduction here is the securing of apposition of fracture fragments without interfering with the growth center of

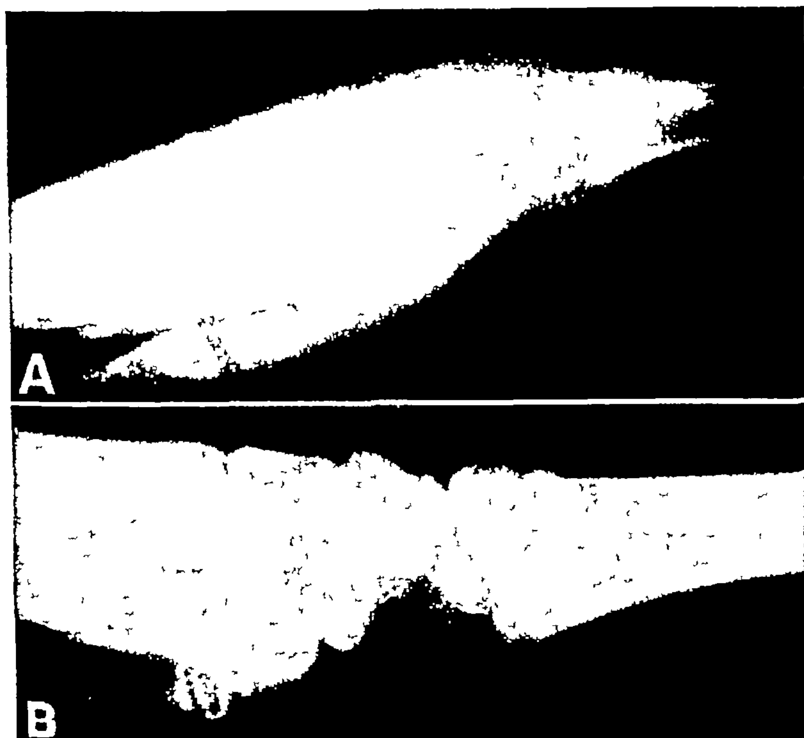


FIG 127 —*A*, mild epiphyseal separation in a boy, 9, which required immobilization only for perfect result. *B*, more severe type with fracture, requiring reduction as well as immobilization.

the bone Formerly it was thought that a cabinet maker's type of reduction was necessary to prevent disturbance in growth Now it has been conclusively proved that minor degrees of deformity tend to correct themselves by growth (Fig 127) One should, therefore, be content with a fair reduction rather than to risk damage to the epiphyseal plate by repeated manipulations Any extensive displacement should be corrected The fragments are pulled apart and reduction accomplished by pressing the lower fragment volarward and the proximal fragment dorsally, at the same time flexing the wrist and keeping the hand in ulnar deviation The

more severe types are often easier to reduce than those with a minor degree of displacement With the wrist flexed, a plaster cast is applied and left on for four or five weeks

Fracture of Anterior Margin of Radius

This fracture, like Barton's fracture, is really a fracture-dislocation with the carpus subluxating anteriorly (reverse Barton's fracture). The cause is usually a fall on the hand with forcible hyperextension of the wrist or, at times, with forcible hyperflexion, the hand striking on the dorsum In any dislocation of the wrist which tends to recur easily this type of fracture should be suspected.

TREATMENT —Reduction is usually not necessary but the wrist should be immobilized in a neutral position A plaster cast is first applied with the wrist in moderate flexion; this dressing is removed at the end of a week or two and another cast applied with the hand placed in a neutral position as regards flexion and extension This cast is left on for about three weeks

DISLOCATIONS OF THE WRIST

Dislocations of the wrist are rare compared to dislocations in the carpal region. To avoid confusion between radioulnar and radiocarpal dislocations and intercarpal dislocations or fracture-dislocations these conditions will be discussed separately

Dislocation of Inferior Radioulnar Joint

Dislocation of the radioulnar joint is usually associated with Colles' fracture of the wrist Less commonly this dislocation occurs when the shaft of the radius is fractured and the ulna remains intact. Still more rarely, dorsal dislocation of the lower end of the ulna may follow forcible hyperpronation at the wrist

In any suspected dislocation at the lower end of the ulna, careful comparison should always be made with the opposite wrist, since many persons have a striking prominence of the ulna due to a very lax radioulnar articulation With true dislocations, the prominence of the ulnar head is readily apparent and, depending on whether the dislocation is anterior or posterior, this prominence will be visible on either the volar or dorsal surface of the wrist Limitation of rotation of the wrist, pain, swelling and tenderness are always present The wrist also looks deformed, being nar-

rower and thicker because the dislocated ulna tends to be thrown on top of the radius X-rays may not show as much displacement as is apparent clinically

TREATMENT—Anesthesia will be required for reduction In isolated dislocations reduction is accomplished by traction accompanied by direct pressure over the ulna and radial deviation of the wrist The arm is then immobilized in a plaster cast with the elbow at a right angle, the forearm in a midposition between pronation and supination and the wrist in slight ulnar deviation Immobilization is maintained for about three or four weeks, and forcible rotation is avoided for at least two more weeks

In dislocations which have existed for more than a few days reduction may be difficult For these, either of two procedures may be used In one an open operation is done, the dislocation reduced and a strip of fascia used as a sling to prevent redislocation In the other procedure, the lower end of the ulna is resected and the shaft prevented from protruding dorsally by fastening it to the flexor carpi ulnaris with a sling of tendon or fascia The latter procedure gives excellent results in young persons This operation requires a knowledge of the surgical approaches to the forearm to avoid injuries to the ulnar nerve When there is an accompanying fracture of the radius, internal fixation of the fracture combined with the sling operation will give a good result

RADIOCARPAL DISLOCATIONS

Simple dislocations in this region are comparatively uncommon The dislocation is usually backward but, rarely, may be forward, medial or lateral (Fig 128) The ligaments around the radiocarpal joint are torn off or avulsed from their bony insertions and there is usually a fracture of the articulating margin of the radius The extensor tendons are stripped up from the posterior surface of the radius, and the flexor tendons and nerves are stretched across the front end of the radius and ulna The navicular and lunate bones rest on the posterior surface of the radius In severe types open wounds occur

POSTERIOR DISLOCATIONS—The deformity is somewhat like the silver-fork deformity of Colles' fracture but there is often more swelling, and on palpation the styloids of the radius and ulna, if they have not been torn off, will be found in normal relationship and the carpal bones can be palpated on the dorsum of the radius The forearm is usually pronated

It is important that prompt reduction of these dislocations be secured because the vessels and nerves which are stretched over the lower end of the radius are in grave danger Strong traction on the hand and a little

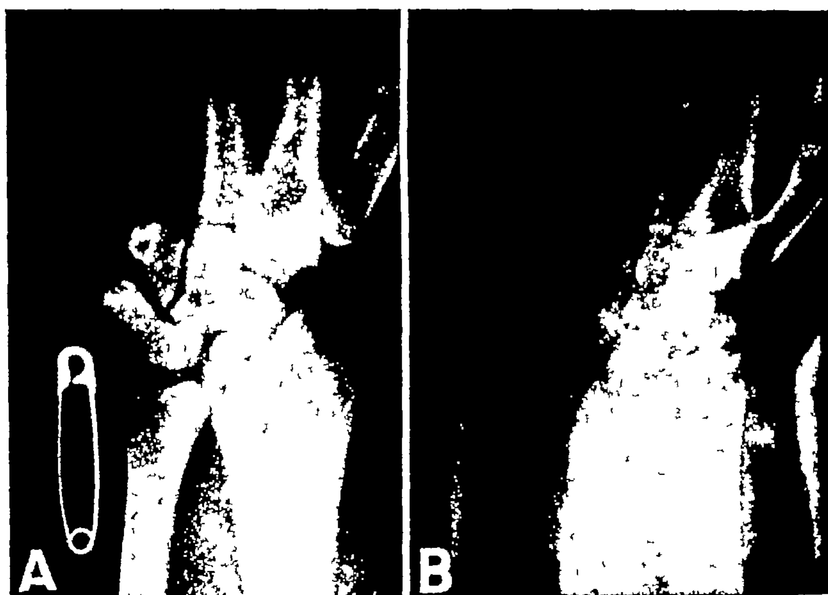


FIG 128 —*A*, medial dislocation of wrist with fracture of both styloids *B*, after manipulative reduction and immobilization in radial deviation and flexion Radial styloid later excised for nonunion with good end result.

pressure over the carpal bones will usually cause the dislocation to slip back into place Any loose chips of bone should be pressed back into place if possible A padded plaster cast is then applied from the middle of the upper arm to the flexion crease of the fingers The wrist is usually put up in a neutral position for the first four weeks and then changed to a position of dorsiflexion for another two weeks

ANTERIOR DISLOCATIONS —This rare injury corresponds to the Smith fracture at the wrist in its cause and in the appearance of the deformity The distal articulating surface of the radius and ulna may be palpated beneath the skin and the hand is anterior to the forearm, with a so-called gardener's spade deformity

Traction accompanied by backward pressure will reduce these dislocations, and one should experiment with the position of the wrist to find out what position will maintain reduction When a sizable piece of the anterior margin of the distal articulating surface of the radius has been fractured along with the dislocation, the hand and forearm should be immobilized with the wrist extended, as for Smith's fracture

FRACTURES OF THE CARPAL BONES

To properly understand and treat injuries of the carpus one should appreciate the functional anatomy of the wrist joint The lunate, triangu-

lar and pisiform bones act as a unit in the proximal row, and the lesser multangular capitate and hamate act as a unit in the distal row. The navicular functions in both rows and links the two rows together. The greater multangular acts as a metacarpal for the thumb The ligamentary attachments binding the proximal row of carpal bones to the radius and ulna and the distal row to the metacarpal bases are apparently stronger than the short ligaments binding the two rows of carpals together

A hyperextension injury, therefore, tends to disrupt the wrist joint through its weakest point—the midcarpal joint Since the navicular is

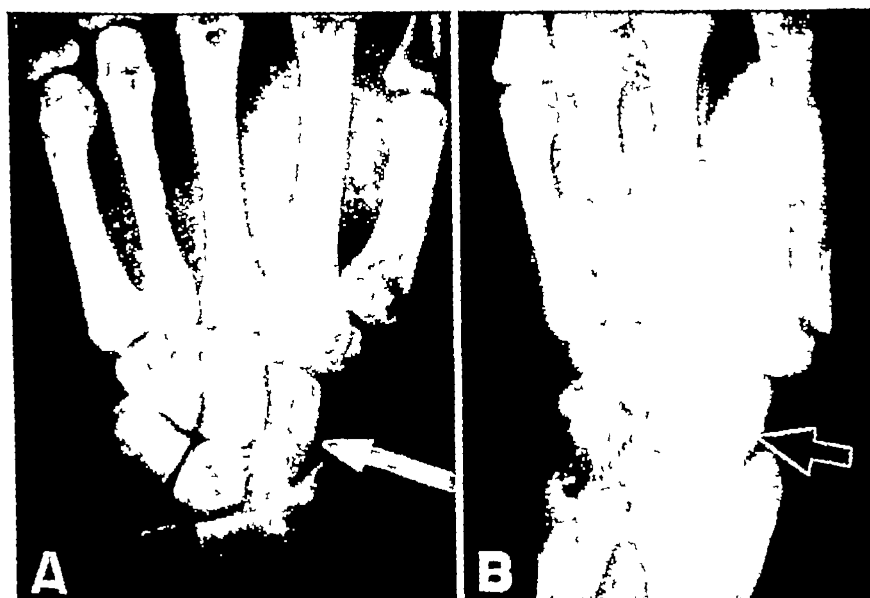


FIG 129—*A*, fresh navicular fracture treated by immediate immobilization *B*, x-ray after three months, showing almost complete healing

attached distally to the base of the thumb and distal row of carpals through the strong radial collateral ligament and proximally to the radius and lunate through the dorsal and volar radiocarpal ligaments, the disrupting force is applied to the waist of the navicular, which is commonly fractured without displacement (Figs 129 and 130) A similar force, creating a more severe injury, carries the distal row of carpals dorsally away from the proximal row with a displacement fracture of the navicular (Fig 135) This is the second commonest lesion encountered Sometimes the force fractures the radial styloid instead of the navicular, permitting escape of either the navicular or lunate (Fig 136)

Although the exact mechanism producing dislocation of the lunate

(Fig 133) is disputed, it seems likely that it is closely related to that producing transnavicular perilunar dislocations, which occur in about the same frequency It seems probable that, depending on the direction of disrupting forces and certain anatomic variations, the volar radiocarpal ligament may rupture first, allowing the lunate to be extruded into the carpal tunnel without fracture or dislocation elsewhere Often, however, during reduction of such a lesion it will become apparent that what appeared to be a simple dislocation of the lunate is in fact a perilunar dis-

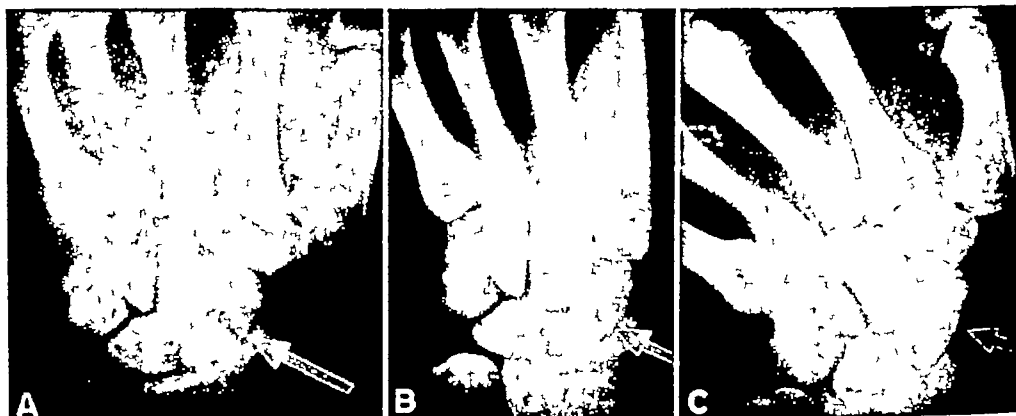


FIG 130—*A*, navicular fracture, showing wide separation one month after injury, without treatment *B*, fracture line still present after six months of immobilization *C*, fracture apparently healed 18 months after injury

location with secondary dislocation of the lunate due to the retrolunar displacement of the capitate Since such displacements are often reduced spontaneously, their pathology is inadequately appreciated

Carruth Wagner of San Francisco lumps all these conditions together under the general title of perilunar dislocations He believes that in any fractured navicular separation of the fragments indicates that a perilunar dislocation existed, with consequent loss of blood supply to the proximal navicular fragment When anatomic restoration of the fragments cannot be obtained he believes that arthrodesis of the wrist is indicated

Fractures of the Navicular †

This is the commonest of the carpal injuries and has been said to com-

† Common usage has carried over certain of the old terms (especially in the English literature) for fractures and dislocations of the carpal bones, with the navicular referred to as the scaphoid and the lunate as the semilunar Mixed terminology is also apparent, e g , trans-scaphoperilunar dislocation In this text BNA terminology is used

prise about one half of 1 per cent of all fractures The patients are usually young males, but the condition is not uncommon in either sex at any age When the outstretched hand strikes the ground, the radius drives forward and all the weight of the body may be transmitted through the navicular bone to the palm The narrowest portion of the navicular is approximately at its center, which lies against the greater multangular bone on one side and the hollow of the radius on the other The force therefore tends to fracture the navicular in its narrow, central part

As a rule, there is little displacement of the fracture fragments The usual fracture line runs directly through the center of the bone across the long axis and in an oblique line with relation to the anteroposterior surface of the wrist However, there may be unequal-sized fragments, and comminution also occurs When the fracture fragments are of unequal size, the lateral is usually the larger and this may be displaced posteriorly. A fairly large proportion of patients have an associated fracture or dislocation of the lunate bone and a fracture of the radial or ulnar styloid Interference with the blood supply of one fragment may be a complication

DIAGNOSIS —In any patient who has a painful wrist following a fall, especially if there is tenderness in the region of the anatomic snuffbox, a fracture of the navicular must be suspected Although considerable swelling in the region of the snuffbox may sometimes be present, symptoms are often minimal Movements of the wrist are painful and somewhat limited, especially forced dorsiflexion and abduction Pressure on the first, second or third metacarpal in its axis may also cause pain at the fracture site Because the ordinary anteroposterior x-rays may not show the fracture, special oblique views should be taken

It often happens that a patient will claim a recent injury of the wrist and x-rays will show an old fracture of the navicular There will be decalcification of the bone and an appearance of cystic change between the fragments rather than the fine crack which is seen when a fracture is only a few days old Decalcification and cystic change indicate a fracture that is not less than six weeks old, if the bone fragments are sclerosed and the surface is densely calcified, the fracture is probably a year old One must also differentiate this condition from a congenitally bipartite scaphoid

TREATMENT —Much disability follows delayed or improper treatment of navicular fractures In patients who seek treatment after several weeks the probability of nonunion is high

Three types of fractures commonly described are fractures of the tubercle, the waist and the proximal pole In fractures of the tubercle, both

bone fragments have a good blood supply, the fracture being extra-articular These fractures always unite, although immobilization for a short period is desirable Fractures of the waist are much the commonest In these, as a rule, both bone fragments have a good blood supply, but the fracture is interarticular and, since there is no natural fixation, union is dependent on complete immobilization In fractures of the proximal pole, approximately one-third will show an impairment of the blood supply to the small fragment In this type it may be necessary to immobilize the wrist for as long as 12 months before union is obtained

In less severe cases, such as those showing only a fine line at the fracture site, and in fractures treated within a short time after injury, immobilization is maintained for about three months (Fig 129) At the end of this time oblique radiographs are taken to ascertain the amount of healing These x-rays never show callus, but the fracture line will be completely obliterated when the bone is healed When there is a suggestion of displacement, indicated by a wider-appearing fracture line, or when the patient does not come for treatment immediately (Fig 130), a more prolonged period of immobilization is required When there is actual displacement of the fracture, traction on the hand and digital pressure over the bone fragments may aid in reduction

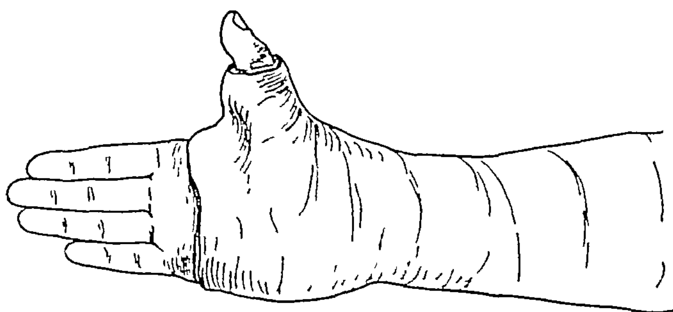


FIG 131 —Cast for navicular fracture

The proper cast immobilizes the thumb as well as the wrist (Fig. 131) A minimum of padding should be used The cast extends from the upper forearm to the base of the fingers, firmly gripping the palm and the metacarpal and proximal phalanx of the thumb but permitting motion of the finger joints and the end joint of the thumb The wrist is held in ulnar deviation and extension and the thumb in abduction and extension Whenever the cast becomes loose, either from atrophy of the parts or subsidence of swelling, it should be removed and a new snug-fitting one applied Union can almost always be obtained provided the bone

fragments are in contact and immobilization is maintained for an adequate period

Delayed union—The commonest causes of delayed union are failure to diagnose the fracture early and failure to immobilize the wrist adequately. Delayed union is evidenced both by the changes shown on x-rays and by clinical findings of tenderness over the snuffbox region and pain when the fist is tightly clenched or the wrist is moved In these cases immobilization sometimes must be persisted in for as long as a year if union is to be secured A tightly fitting plaster cast can be worn and the patient allowed to return to work if his occupation will not cause excessive trauma to the wrist The best cast for this purpose is an unpadded cast of some nonwettable material. About half the patients treated by prolonged immobilization suffer some discomfort on hard use later

Established nonunion—This condition is recognized by the x-ray appearance of decalcification of the bone fragments and sclerosis of the fracture line without evidence of healing after six months Use of the cast may then be discontinued and the patient tries using the hand in his work to test for pain When pain is present, there is no alternative but to select some surgical procedure Drilling with bone grafting of the fracture fragments may be successful, provided avascular necrosis of one fragment or osteoarthritis of the wrist has not developed Bone grafting should be undertaken only by one who is thoroughly familiar with the surgical approaches to the wrist joint The drill must pass through both fragments in the long axis of the navicular, the fragments being pressed together and drilled under actual vision X-rays guide the depth of drilling The drill hole is enlarged to approximately ¼ in and a peg of bone taken from the ulna or ilium is then fitted into the hole The wrist should be immobilized for a minimum of four months

When a small fragment of bone is detached and becomes avascular, this fragment may be removed Although the wrist may be somewhat weakened thereby, a fairly good result will be obtained if arthritis does not develop Excision of the fragment does little to prevent the progress of arthritis that is already present In all cases in which a part or all of the bone is excised, a shift in the carpus occurs, apparently from the capitate attempting to fill the space This is followed by limitation of motion in about 30 per cent of patients However, for ordinary activity there are few complaints if only a part of the bone is removed, when all the navicular is removed, results are not too satisfactory. The experience of industrial accident boards and insurance firms would seem to substantiate this

In patients with sedentary occupations who can put up with the dis-

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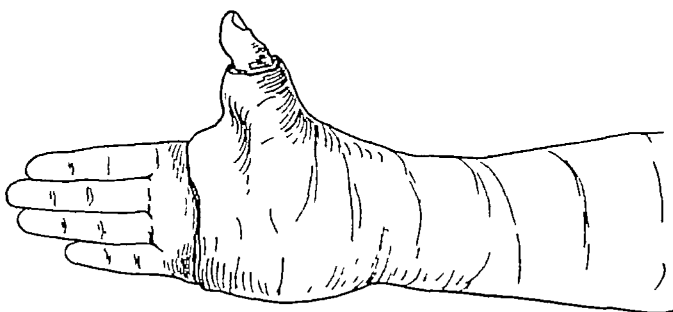


FIG 131 —Cast for navicular fracture

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from the upper forearm to the flexion crease of the palm and with the wrist in a neutral position

CHIP FRACTURES OF TRIANGULAR BONE —These fractures are caused by a backward fall on the hand, the triangular bone being caught between the pisiform and the lower end of the ulna as the force strikes the ulnar border of the hand Such fractures usually heal even without immobilization

KIENBOCK'S DISEASE ‡

A great many different explanations have been offered for the cause of this uncommon condition The disease is actually a progressive aseptic necrosis of the lunate bone, culminating in its more or less complete collapse and followed by considerable permanent disability of the wrist The presence of a short ulna has been postulated as being necessary to the development of Kienbock's disease The lunate is subjected to greater stresses when this anatomic variation is present However, the trauma to which the lunate is subjected, especially on its proximal surface where the disease makes its first appearance, makes it exceedingly likely that the initial exciting factor is a fine stellate and fissure fracture The aseptic necrosis which develops is due to the meager blood supply, the lunate having the poorest blood supply of all the carpal bones

PATHOLOGY —The lunate bone is compressed in its short axis and its proximal and distal articulating surfaces are irregular The cartilages also present areas of fracturing and cystic degeneration Beneath these fractures there may be loss of supporting bone As the process continues, the necrotic bone is replaced by fibrous scar tissue and a little new bone formation The predominant pathologic picture common to all microscopic examinations is bone necrosis There are no signs of inflammatory reaction

DIAGNOSIS —Whenever the distal ends of the radius and ulna do not bear a normal length relationship and there has been an injury to the wrist, or clinical signs are developing even without a history of an injury, the clinician should be on the lookout for Kienbock's disease The lunate should be carefully examined radiographically and the radiologist should look especially for fine fissure fractures on the proximal surface of this bone or for signs of minute compression fractures, the earliest findings in this disease If the initial films fail to reveal any abnormalities except a

‡ The material in this section is a condensation of a monograph by Dr Wilmer C Smith, used by permission

comfort and weakness, nothing need be done These patients may repeatedly "sprain" the wrist and will need immobilization for these sprains For anyone engaged in manual labor an arthrodesis of the wrist is usually necessary, the wrist fixed in about 20 degrees dorsiflexion and slight ulnar deviation, with a bone graft placed between the radius and carpus

In summary, the best results in fractures of the navicular will be obtained in those cases in which union is secured by simple immobilization In fact, the majority of orthopedic opinion favors prolonged immobilization over any form of operative treatment for most of these fractures The poorest results will follow improper or unsuccessful operative procedures carried out in the presence of arthritis Mediocre to fair results will be obtained with operative procedures which circumvent arthritis and do not weaken the wrist excessively Occasionally very old cases are seen in which the strength and general usefulness of the hand are almost normal In these, no treatment is necessary as long as complaints are minimal When the function of the hand is seriously impaired by pain, an arthrodesis is indicated

Fractures of Other Carpal Bones

Lunate (semilunar) bone —This bone is rather frequently dislocated but is rarely fractured However, when the hand is swung into the position of ulnar deviation the bone may be caught between the lower end of the radius and the greater multangular and compressed

In fractures of the lunate bone, considerable pain and swelling in the wrist region are associated with limitation of motion and weakness of grip There is also point tenderness over the fractured bone X-rays are absolutely essential to confirm the diagnosis These fractures should always be immobilized in a snugly fitting plaster cast in the position of function The cast should be worn for about two months and exercises of the fingers persisted in during this period

Carpals other than navicular and lunate —Any of the carpal bones may be broken as a result of direct violence, such as a blow or crushing injury In carpal bones other than the navicular and lunate, displacement is usually not great and healing always occurs, since these bones are well supplied with blood vessels and do not tend to become displaced once reduction is obtained Reduction is easily accomplished by traction and direct pressure on the fragments Immobilization should be maintained for an average of seven weeks with a plaster cast extending

from the upper forearm to the flexion crease of the palm and with the wrist in a neutral position

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shortening of the ulna, subsequent films should be made after one and three months to ascertain any changes in the lunate bone

The disease may progress without clinical symptoms, but radiographic examination will disclose minute cysts together with areas of increased and decreased density These develop between one and four months. Later loss of definition of the radial border, often with fragmentation in this area, and further cyst formation are noted Eventually collapse takes place (Fig 132) Sclerosis now occurs and there may be gaps in the bone The appearance of sclerosis is due not to eburnation but to the presence of

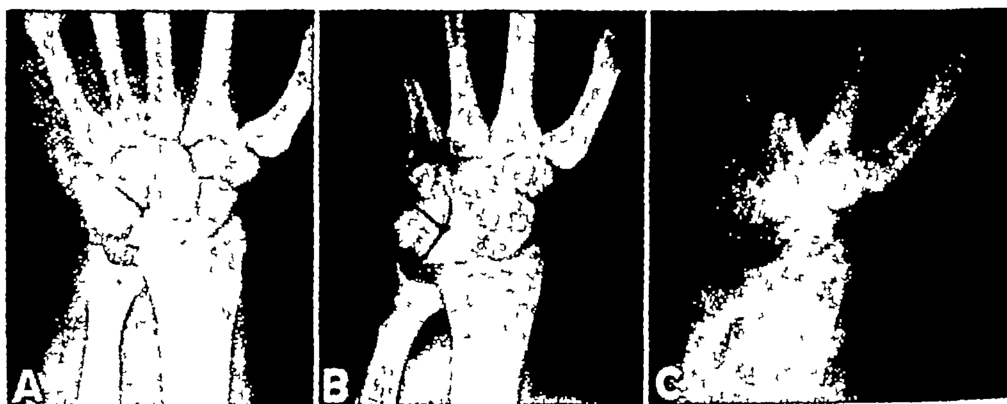


FIG 132 —Moderately severe Kienbock's disease treated by prolonged immobilization without relief, followed by excision of lunate bone with decided improvement. *A,* at onset of symptoms, *B,* 12 months later, *C,* after excision (Courtesy of Dr C E Carlson)

calcareous detritus This condition is not to be confused with a fresh fracture There is bone necrosis before collapse, and collapse usually does not occur until at least six months after the original injury

Signs and symptoms during the initial period of a few days or weeks include pain, swelling and disability in the wrist, with loss of grip and pain on motion During the second stage which lasts from one to several months there are only vague complaints about the wrist, perhaps some slight pain at the limits of motion and negative physical findings In the third stage pain returns, together with weakness and tenderness As the lunate collapses, symptoms may gradually or suddenly increase There are then loss of dorsi- and volar flexion, weakness of the grip and a dull aching, especially after use Examination shows a thickened wrist with localized tenderness over the lunate As the wrist stiffens some of these symptoms become less severe

TREATMENT —Early cases require immobilization for at least eight weeks with frequent subsequent radiographic check-ups to make sure the

process has been arrested When the condition is of intermediate severity with some cystic change but without definite collapse, immobilization for about six months is necessary Again check-up radiographs are essential After collapse has taken place the decision must be reached as to whether excision of the bone will benefit the hand After excision of the lunate bone the carpal bones tend to regroup themselves, and a certain amount of osteoarthritis results The mechanics of the wrist are not improved by the operation but the period of treatment is shortened

Immobilization, if used, must be continued for several months Wrists immobilized for more than five months have been observed to have less deformity and better function than those immobilized for shorter periods Immobilization for less than two months almost always gives poor results The age of the patient and the amount of deformity are the factors that determine the extent of osteoarthritis During the early periods of immobilization the fingers should not be used forcibly, because the action of the forearm muscles is transmitted to the lunate When the hand is first put up in plaster, palmar flexion may be advantageous to relax the flexor muscles

CARPAL AND INTERCARPAL DISLOCATIONS

Besides the common dislocation of the lunate, a variety of dislocations may occur in the carpal region The distal row of carpal bones may, for example, be dislocated around the lunate and the complete navicular, around the triangular and lunate or directly through the midcarpal joint The discussion to follow takes these up in the order of their frequency

Dislocation of the Lunate

This condition is a fairly common injury of the wrist, occurring next in frequency to fractures of the navicular The lunate lies in a pocket on the lower end of the radius and, when the wrist is extended, its anterior surface is not protected by an adjacent carpal bone In any fall on the outstretched hand, therefore, the force of the blow may push the lunate forward between the end of the radius and the capitate Then, with rupture of the joint capsule, either the lunate is extruded forward with the capitate coming to lie against the radius or the capitate slips over the top of the lunate to produce a perilunar dislocation of the carpus

Pathology—In forward dislocations the dorsal ligament of the lunate is torn while the anterior ligament remains intact The bone then rotates about 90 degrees toward the palm of the hand and the dorsal

surface comes to face downward Occasionally both the anterior and posterior ligaments are torn The bone then loses its blood supply and undergoes aseptic necrosis There may be an accompanying fracture of the navicular, with a portion of this bone dislocated along with the lunate After anterior dislocation the bone lies beneath the transverse carpal ligament on the front of the wrist in the space which is commonly filled by the flexor tendons and the median nerve In a considerable number of cases there is a certain degree of median nerve palsy Rarely the bone may be dislocated posteriorly by a fall on the flexed wrist Under these circumstances, the dorsal ligament remains intact and the anterior ligament is

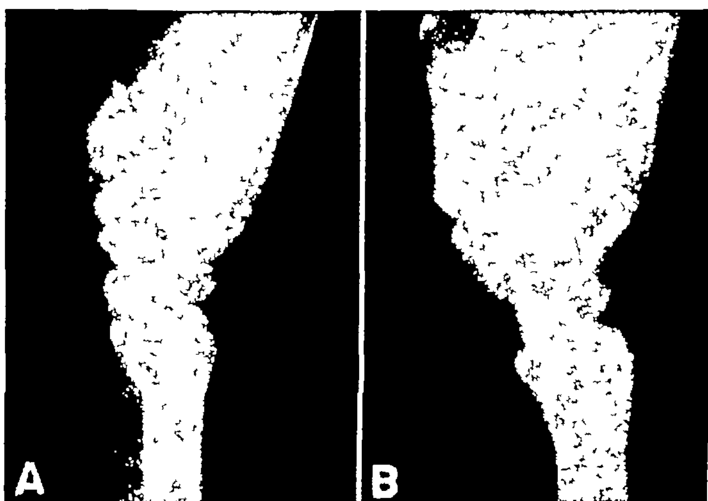


FIG 133 —*A*, anterior dislocation of lunate bone due to a 30 ft fall into sand pit, median nerve also injured *B*, after reduction

ruptured, and the bone is dislocated into the space under the extensor tendons on the back of the wrist

DIAGNOSIS —The typical clinical findings in forward dislocations are swelling and thickening on the front of the wrist, pain and limitation of wrist motion, immobility of the fingers and numbness and tingling in the distribution of the median nerve The fingers are slightly flexed and extension of the fingers or the wrist is painful Palpation will reveal the bone to be deep on the anterior surface of the wrist, with normal relationships of the styloid processes and the other bones The x-ray appearance is quite typical, the lateral view showing the forward displacement and rotation of the lunate (Fig 133)

In posterior dislocations the situation is reversed The bone is palpable on the dorsum of the wrist and the patient resists flexion of the fingers or wrist Neurologic changes are not evident

TREATMENT—Manipulative reduction can usually be accomplished in early cases but may not be possible after a week or two The surgeon should be familiar with the several methods of reduction because the vagaries of this dislocation are such that one method may not succeed however often tried, whereas with another reduction may be easy The method most commonly recommended is best carried out by the operator

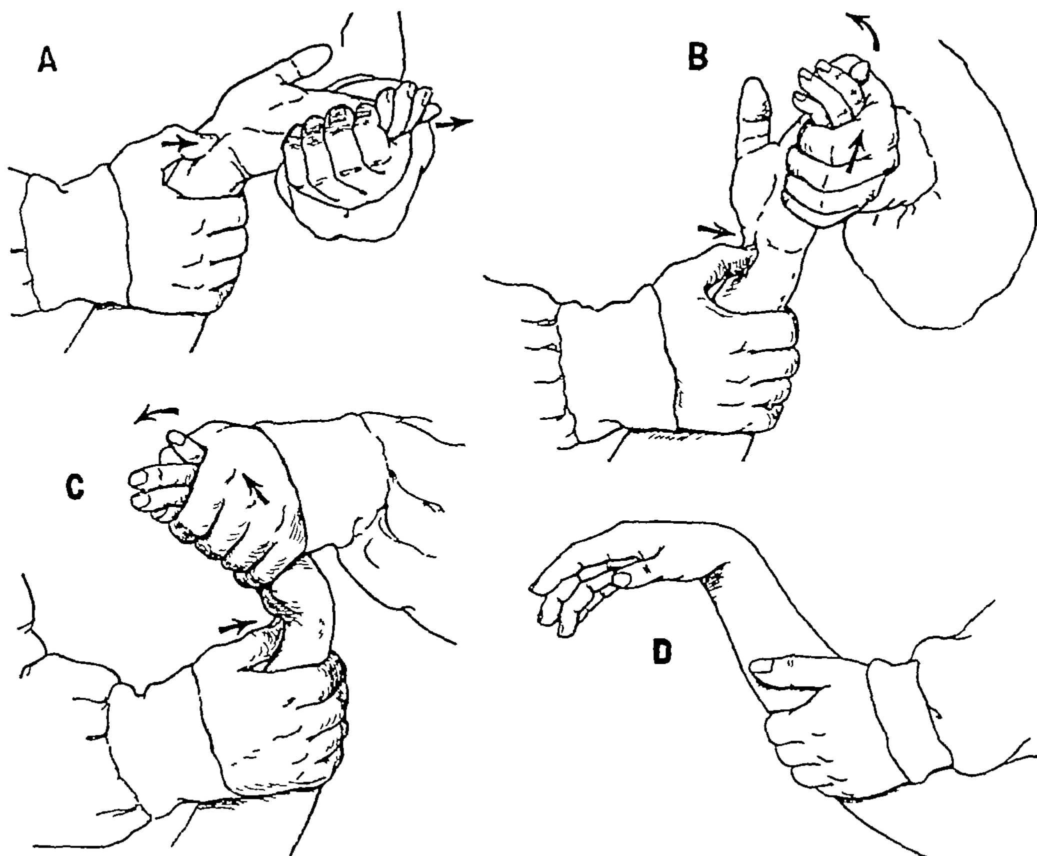


FIG 134—Reduction of dislocation of lunate (semilunar) bone *A*, extension of wrist with traction, and pressure on lunate with operator's right thumb *B* and *C*, flexion of wrist with continued traction and pressure on lunate *D*, test for reduction

working with an assistant The assistant hyperextends the wrist and makes traction on the fingers, and the surgeon makes traction on the wrist and, with his thumbs placed over the dislocated bone, forces the bone back into place When the bone is felt to snap into place the wrist is flexed to hold it in position This maneuver may also be done by the surgeon working alone, the hyperextension and traction on the hand being accomplished by one hand and the traction on the wrist and pressure on the bone being accomplished by the other (Fig 134). It should be remem-

bered that pressure is being made directly over the median nerve and that excessive force may bruise this structure

Reduction is really more of a trick than a question of force If the capitate can be pulled around into the cup of the lunate by continuous traction and the lunate can be held from becoming further dislocated forward, less force will be required than if an attempt is made to press the bone into position with the wrist extended At times these dislocations can be reduced by grasping the forearm and flapping the hand back and forth At other times a little traction with a quick hyperextension followed by flexion will be successful.

When these methods fail, skeletal traction or operative reduction must be used A small Steinmann pin or Kirschner wire is passed through the neck of the metacarpals and another through the olecranon process These pins are placed in a mechanical traction apparatus and the apparatus manipulated so that strong traction is applied The surgeon then presses with both thumbs over the front of the bone Continuous traction is contraindicated.

Operative reduction is usually necessary after two or three weeks have elapsed, because the bone becomes adherent to the anterior capsule of the wrist. The carpal region is approached through an anterior incision, preferably detaching the transverse carpal ligament along its ulnar side from the pisiform and hamate The median nerve and flexor tendons are retracted, exposing the displaced bone This may then be removed or replaced in position. Traction must be made to evict the hamate from the space normally occupied by the lunate Although the lunate will stay in position if replaced, a badly damaged bone should be removed The wound is closed and the wrist immobilized for about two weeks Finger exercises are begun immediately

Replacing the bone after several weeks is not recommended because what little remaining blood supply the bone has is usually destroyed by the operation, and avascular necrosis follows The wrist joint undergoes arthritic changes both in the midcarpal and radiocarpal joints, with disabling stiffness and pain Occasionally old cases are seen in which the nerves and tendons have accommodated themselves to the narrowed space in the carpal canal and no complaints are present. In these, no treatment is indicated. For the most part, a normal wrist cannot be expected following operative reduction or excision.

Whether reduction is carried out by manipulative or operative means, the wrist should be immobilized in a position which will maintain the reduction Manipulative reductions usually require immobilization in flex-

ion for about a week, after which immobilization should be continued in the position of function Because it is not always possible to determine clinically whether or not full reduction has been accomplished, the wrist should be x-rayed after reduction It is important that sufficient finger movements be carried out to prevent stiffening and tenosynovitis

Backward dislocations of the lunate are treated by manipulation which is the same as that for forward dislocations except that the wrist is flexed while traction is applied to open up the space for the lunate and pressure is made over the dorsum of the wrist The wrist is then hyperextended and immobilized in an extended position

Transnavicular Perilunar Dislocations

Next to anterior dislocations of the lunate, the most common dislocation in the carpal region is the transnavicular perilunar. This is not seen especially often and x-rays may be misleading, the injury sometimes being

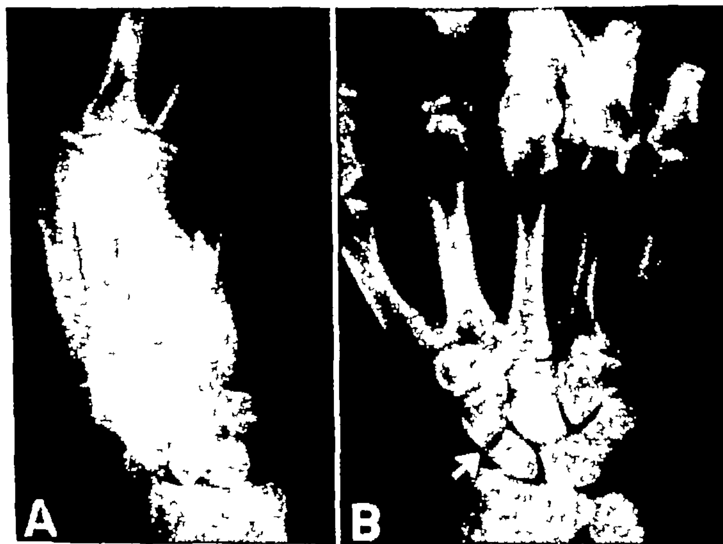


Fig 135 —Transnavicular perilunar dislocation, *A*, before, and *B*, after reduction

diagnosed as a dislocated lunate, a fractured navicular or a congenital abnormality of the carpus

The injury is similar to the simple anterior dislocation of the lunate, the proximal fragment of the navicular usually going forward with the lunate, and is probably caused by the same mechanism The signs and symptoms are approximately the same, and x-rays are necessary to distinguish the two (Fig 135)

PATHOLOGY —There is always a severe ligamentary injury, with chip fractures of the carpal bones, damage to the articular cartilages and frequently a fracture of the styloid process There may be fractures of the capitate, triangular, pisiform or one of the metacarpals In approximately half the cases there is some degree of avascular necrosis of the proximal fragment of the navicular Median nerve palsy is common

DIAGNOSIS —There is an increase in the thickness of the wrist in the midcarpal level, and the backward displacement may be apparent before swelling obscures the bones The proximal margin of the capitate may be palpable on the dorsum The hand is held in a position of a slight radial deviation and there is restriction of motion of the wrist and fingers

TREATMENT —The same type of manipulation used for simple dislocations of the lunate is applicable for these fracture-dislocations However, reduction is more difficult and open reduction more often required After reduction, the wrist should be immobilized in palmar flexion for three weeks and thereafter in the neutral position until the scaphoid is united Nonunion of the navicular is treated as previously described

After two or three weeks unreduced dislocations usually require open reduction When open reduction is necessary, the lunate and the displaced portion of the navicular are usually removed. The proper bones are most easily approached through an incision on the dorsum The extensor tendons of the fingers are easily retracted out of the way, but retraction of the extensors of the wrist is more difficult because of their nearby insertion in the bases of the metacarpals An L-shaped incision in the skin and dorsiflexion of the wrist will aid in exposure and retraction of the extensor tendons

The dorsal radial lunate ligament should be preserved and the wrist replaced over the lunate with a minimum of ligamentous stripping, if the bones are not removed

When the proximal fragment of the navicular undergoes avascular necrosis, three treatment methods are available bone grafting, excision of the avascular fragment or continued immobilization, as described in the preceding section on fractures of the navicular (pp 262 ff)

Prolonged immobilization is necessary for the navicular fracture After the first three weeks the wrist can be brought back into a neutral position and a new cast applied to include the proximal portion of the thumb In some cases even though avascular necrosis is suggested by x-ray a good result will be obtained

Perilunar Dislocations

This injury is the opposite of forward dislocation of the lunate The lunate remains in normal position while the other carpal bones are dislocated backward (Fig 136) Reduction is by traction and forward flexion of the wrist, as in transnavicular perilunar fractures A plaster cast is applied with the wrist flexed, and after three weeks the cast is removed



Fig 136 —*A*, unusual perilunar dislocation with fracture of radial styloid and partial anterior dislocation of lunate *B*, after reduction by traction with pressure over lunate

and active exercises begun Occasionally old cases are seen in which there is fairly good function with little pain but considerable limitation of motion In these, surgery cannot be expected to produce much improvement

Dislocation of the Navicular

This is a comparatively rare condition, comprising about 1 or 2 per cent of all carpal dislocations The wrist becomes locked in ulnar deviation and the dislocated bone can be palpated near the radial styloid Reduction can be accomplished by traction and direct pressure on the displaced bone The wrist should be immobilized in dorsiflexion and radial deviation for about a month A good result should be obtained

Dislocation of Midcarpal Joint

This injury is rare and is usually caused by a fall on the hand The distal row of carpal bones is displaced backward on the proximal row The

ligaments around the joint, including those extending from the bases of the metacarpals to the radius and ulna, are torn and the tendons and nerves in the carpal canal are displaced

As in other dislocations in this region, reduction by traction and pressure on the displaced distal bones is usually effective Immobilization should then be effected by a plaster cast which extends from the upper forearm to the base of the fingers This cast is left on from four to six weeks

Other Carpal Dislocations

In various direct blows or in the twisting and crushing injuries sustained in machinery accidents, any of the carpal bones may be dislocated These dislocations are usually complicated by soft tissue injuries of a severe nature and by fractures or dislocations of the metacarpals, carpometacarpal joints or other carpal bones

The greater multangular has been dislocated both forward and backward Even if replacement is not possible or is not attempted, a fairly good result is obtained In one patient, the lesser multangular was completely dislocated backward and rotated 180 degrees (Fig 137) This required open reduction which was done two weeks after the original repair, a fairly good result was obtained, the bone remaining viable and no arthritis developing after a year The capitate and greater multangular may be dislocated, the capitate carrying the third and fourth metacarpals with it and the greater multangular, the second metacarpal This condition may require open reduction Immobilization should be continued for two to three months

Anterior dislocations of the lunate with perilunar transnavicular fracture-dislocation have also been described In this condition the hand is displaced dorsally and radially, and finger and wrist motions are greatly restricted After reduction, the wrist should be immobilized in palmar flexion and ulnar deviation for about four weeks There is apt to be some permanent disability

FRACTURES AND DISLOCATIONS OF THE METACARPALS AND PHALANGES

Treatment of fractures of the long bones of the hand may be said to mimic in miniature the methods used elsewhere in arm or leg, with one important difference—since mobility and function to allow grasp are all

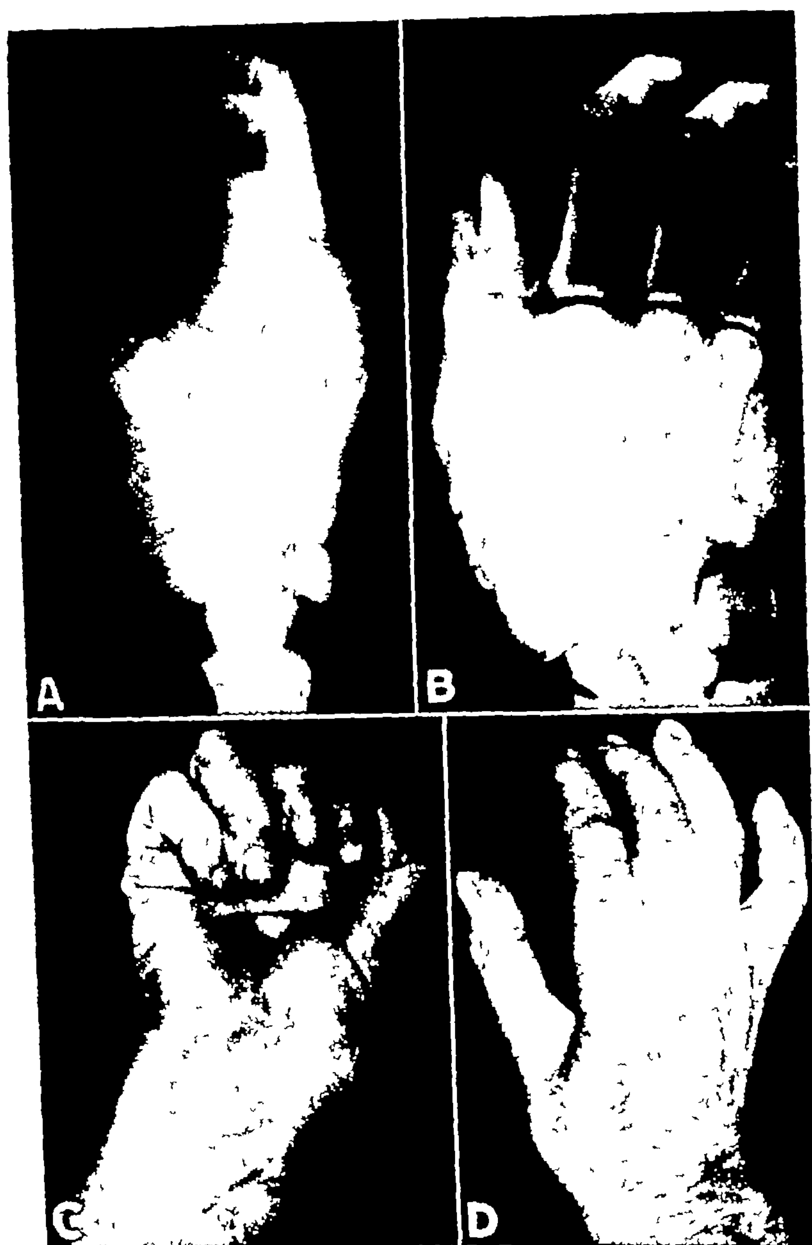


FIG 137 —*A* and *B*, dislocation of lesser multangular with associated fracture or dislocation of metacarpals (through-and-through wound of wrist by baling machine) Replaced by open operation, with bone apparently viable two years later *C* and *D*, end result

important, alignment and even union are secondary Here, as anywhere else, the simplest method is often the best If the fracture can be "set" and splinted until healed, the result will usually be better than if some complicated apparatus or operative procedure is used The general opinion of British orthopedists is that the body has a natural propensity for healing fractures and that interference, operative or otherwise, may delay recovery and result in stiff joints, wasted muscles or circulatory impairment They believe that no treatment at all is indicated in many hand fractures I do not share this enthusiasm for therapeutic nihilism. The fine balance of the hand can be upset by malalignment of the metacarpals or proximal phalanges Briefly, two types of fractures occur—those that are *stable* when set and those that are *unstable* Stable fractures require only splinting, with the distal fragment always brought around into alignment with the proximal to relax muscle pull Unstable fractures usually require operative intervention Intramedullary nailing, or cross pinning, has been a big help in management of these fractures Traction devices seem to have fewer advocates with the passage of time, and while some injuries require their use I believe that they should be avoided and their use reserved for certain comminuted cases

Fractures of the Metacarpals

Metacarpal fractures are rather common, resulting from crushing injuries of the hand, direct violence or indirect violence, as in fist fights Bennett's fracture, a fracture of the base of the thumb metacarpal, is actually a fracture-dislocation of the carpometacarpal joint and will be described as a separate entity

Pathology —Those fractures caused by crushing injuries are usually transverse, and the injury to the soft parts may be pronounced Compounding is common, and complications may include lacerations of the tendons, dislocation of the carpometacarpal joints or carpal bones and pronounced swelling In fractures due to a punch the bone is usually broken near its neck, or the force is transmitted to the base where impaction and spreading occur Whenever there is displacement, there is some posterior angulation at the fracture site due to the pull of the interosseous muscles and the flexor tendons In oblique fractures the combined action of the tendons and interossei causes shortening as well as angulation and, depending on the direction of the force, the shaft fragments will be displaced medially, laterally, anteriorly or posteriorly Whatever the direction of the displacement, the head of the metacarpal is always tilted forward into the palm as shortening takes place

DIAGNOSIS —In addition to the usual symptoms of pain, swelling and deformity, the history of an injury and the exposed position of the metacarpal bones make diagnosis of these fractures relatively easy Inspection will often reveal obvious deformity with obliteration of the prominence of the head of the fractured bone due to ventral angulation and shortening In instances in which little deformity is present, shoving up on the affected digit will cause pain Point tenderness can be demonstrated over the fracture site and gripping of the patient's hand causes pain in the fracture region X-rays are obligatory

GENERAL PRINCIPLES OF TREATMENT —The simplest method which will maintain alignment of the fracture fragments and keep the hand in the position of function is best If alignment is good and only a small amount of shortening is present, a much better functional result will be obtained by ignoring the shortening than by attempting to correct the shortening at the cost of crippling stiffness or delayed union from various traction appliances The bad results seen in these cases are due to angulation at the fracture site, nonunion and crippling stiffness of the fingers These are all avoidable

FRACTURES OF SECOND TO FIFTH METACARPALS

UNDISPLACED FRACTURES —These are usually long oblique fractures with a little shortening but good alignment (Fig 138), transverse fractures with minimum displacement, or impacted basal fractures Treatment of these fractures is eclectic The British simply fix the finger to one of its neighbors with an elastic band The fingers flex together, and this prevents rotation deformity However, a better method is to apply a carefully fitted plaster cast, using a minimum of padding The cast extends from the upper third of the forearm to the distal palmar crease (Fig 23) The wrist is moderately cocked up, and no part of the thumb should be included in the cast The patient is encouraged to move the finger joints as soon as possible, but he should not carry heavy objects or push with the fingers It is well to secure an x-ray a few days after the cast is applied to be sure that there is no additional displacement After three weeks the cast is removed and active use started

DISPLACED FRACTURES —In fractures with displacement, the fragments must be reduced and reduction maintained until healing has taken place Usually a manipulative reduction by traction on the digit and pressure over the fracture site will correct the malposition, and use of traction on the flexed finger will maintain reduction Rotation of the fracture frag-

ments which sometimes occurs should be corrected or, after healing, the fingers will tend to cross on clenching of the fist Rotation can be detected by comparing the surface of the fingernails of the affected hand with the normal mate The flexed finger tips should all point toward the tubercle of the navicular

After reduction, a snug-fitting plaster cast is applied, with the wrist immobilized in extension to relax the pull of the extensor carpi muscles on the proximal fragments The cast should extend as far as the distal palmar crease to support the distal fragment and allow flexion of the



FIG 138—Spiral fractures of fourth and fifth metacarpal shafts with some shortening but good alignment. Immobilization in plaster cast for one month without traction resulted in full function

fingers to about 90 degrees (Fig 139) A loop of wire, slightly wider than the involved finger and long enough to extend a couple of inches beyond the finger, is incorporated in the cast on its volar surface The wire loop is padded to prevent pressure on the finger and is bent so that each joint of the finger will be flexed about 45 degrees Traction can be obtained with the finger flexed 45 degrees, and relaxation of the interossei is better and subsequent stiffening of the metacarpophalangeal joint is less than with flexion of smaller degree The most satisfactory method of applying traction is to insert a small stainless steel wire pin through the pulp of the distal segment of the finger This pin should pass transversely through the finger at a point approximately halfway along the nail and

should be as close to the ventral surface of the bony phalanx as possible

A number of other methods of applying traction are sometimes useful A fine Kirschner wire may be passed through the head of the proximal phalanx of the finger, allowing the distal two joints of the finger to be free In this method, the traction is applied to the axis of the first segment of the finger, with the metacarpophalangeal joint being flexed to about 45 degrees Bohler recommends treatment by traction with the proximal joints flexed only 20 degrees and the middle and end joints flexed to about 90 degrees to maintain reduction when there is severe displacement Angulation of this degree may produce permanent flexion contractures

Immobilization should be maintained for approximately four weeks. During this time the adjacent fingers and the rest of the extremity should not be permitted to become stiff from lack of use

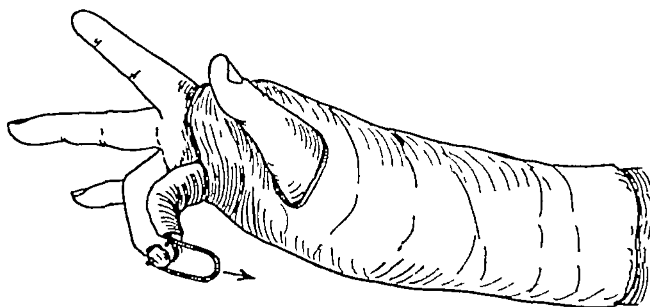


FIG 139 —Cast with outrigger for traction on fractured metacarpal or fractured finger Traction apparatus not shown

It should be emphasized that the traction splint is used to maintain position and *not* to distract the fragments If the bone fragments cannot be maintained in good position with the finger joints flexed at 45 degrees and *mild* traction, operative intervention is indicated (Fig 142)

IRREDUCIBLE FRACTURES —Most metacarpal fractures can be treated successfully by manipulative reduction and immobilization, with traction if necessary Slight lateral displacement is of no particular consequence, but dorsal angulation, if not corrected, causes stiffening of the metacarpophalangeal joints and interferes with the mechanics of the hand Occasionally a metacarpal fracture is encountered which cannot be satisfactorily reduced by manipulation

Open reduction and internal fixation are then required and will be highly satisfactory in selected cases It is important to have sound skin to operate through, since any infection leads to severe crippling Local anesthesia may be used, but general anesthesia is probably more satisfac-

tory and less painful Preparation of the entire hand and forearm should be carried out as described in Chapter 2 The use of a tourniquet is optional but will do no harm and will make the operation easier

If one or two adjacent metacarpals are fractured, a short vertical incision on the dorsum of the hand affords the easiest exposure. For fractures of more than two metacarpals a transverse incision is better The aponeurosis between the extensor tendons is split, the tendons retracted and the fracture located The periosteum in a fresh fracture will usually not require much stripping Reduction is accomplished under direct vision If the fracture stays reduced, nothing further need be done In unstable fractures it is usually easy to maintain reduction by passing a small wire through drill holes in the fragments If this method is not applicable, a miniature Sherman plate may be applied

Whenever open reduction and internal fixation are used the operator should try to get a cabinet maker's reduction, otherwise delayed union or nonunion is likely to result After the bone has been replaced and held in place, the wound is closed with the smallest possible amount of suture material Compression dressings and a light plaster cast are applied The fingers are allowed to flex naturally and early movement of the finger joints is encouraged If any difficulty has been encountered in getting a good solid plating or wiring at the time of surgery, the hand should be immobilized with the metacarpophalangeal joints flexed to about 45 degrees

Many other methods have been suggested, and some of these in the hands of those who are thoroughly familiar with them are highly successful Berkman and Miles's method consists of holding the fractured metacarpal by two or more transverse Kirschner wires, which pass through it and the adjacent normal metacarpals Bunnell fastened the fractures together by small Kirschner wires either skewered obliquely through the fracture site or passed up the medullary cavity of the metacarpal Watson-Jones advocates the use of a small intramedullary bone peg taken from the tibia to hold the bone fragments in position and promote union This method is unquestionably sound, since bone graft is supplied as well as internal fixation, but it is a method to be used only by those highly skilled in bone surgery

Intramedullary nailing is also recommended for fractures of the metacarpals In Campbell's method the fracture site and the base of the affected metacarpal are exposed, a hole is made in the base, and the drill is first inserted perpendicularly and then gradually brought around to an obtuse angle A slot is formed by two or three such holes and a Kirsch-

ner wire is introduced into the proximal fragment until it emerges at the fracture site The fracture is reduced and the intramedullary pin is driven far enough into the distal fragments to make the fracture site secure The end of the wire is embedded in the slot or twisted so that it will not irritate the skin The wire is left in place 8 to 10 weeks Immobilization is omitted when only one metacarpal is fractured With multiple fractures or with fractures at the neck, a molded plaster splint is left on for three weeks

With open displaced fractures, probably the easiest method is to expose the fracture and drill the Kirschner wire up the distal fragment and out through the metacarpal head (with the finger flexed) The wire is then cut off at the fracture site, and with the drill attached to the wire projecting from the metacarpal head, the fracture is reduced, the wire is then back-drilled into the proximal fragment (Fig 141, Plate 2, *A*) The wire end should be cut off and pushed beneath the skin Splinting as shown in Figure 151 is applied

Intramedullary nailing has some definite advantages as well as limitations Severe infections throughout the bone have followed its use, as have complications from technical difficulties It is not as foolproof as simpler methods, however, if properly handled it will give excellent results

Always bury both ends of the pin.

Fractures of the Neck of Metacarpals

A fracture of the neck of a metacarpal often is referred to as a "punch fracture" and is one of the common fractures of the hand The usual site is in the fifth metacarpal, but it may also occur in the second The symptoms are those of pain, swelling and limitation of motion of the finger common to all metacarpal fractures

Examination shows localized tenderness and palpation will reveal depression of the head of the metacarpal Most of these fractures are impacted and, without treatment, many of them heal with angulation and with surprisingly little disability although there is some loss of power in the hand

Since this fracture is impacted and near the head of the bone, attempts to reduce it by traction or by extending the finger are useless Open reduction is never necessary and is mentioned only to be condemned The method devised by Jahss in 1938 is satisfactory With the finger sharply flexed at the metacarpophalangeal and proximal interphalangeal joints, the operator presses the shaft of the proximal phalanx backward, at the

same time pressing the shaft of the metacarpal forward (Fig 140) Disimpaction and realignment of the fracture fragments are thereby accomplished A plaster cast is applied to immobilize the wrist and hand, a felt pad is then applied over the finger and a plaster strip incorporated in the cast and pressed over the extensor surface of the flexed finger A little

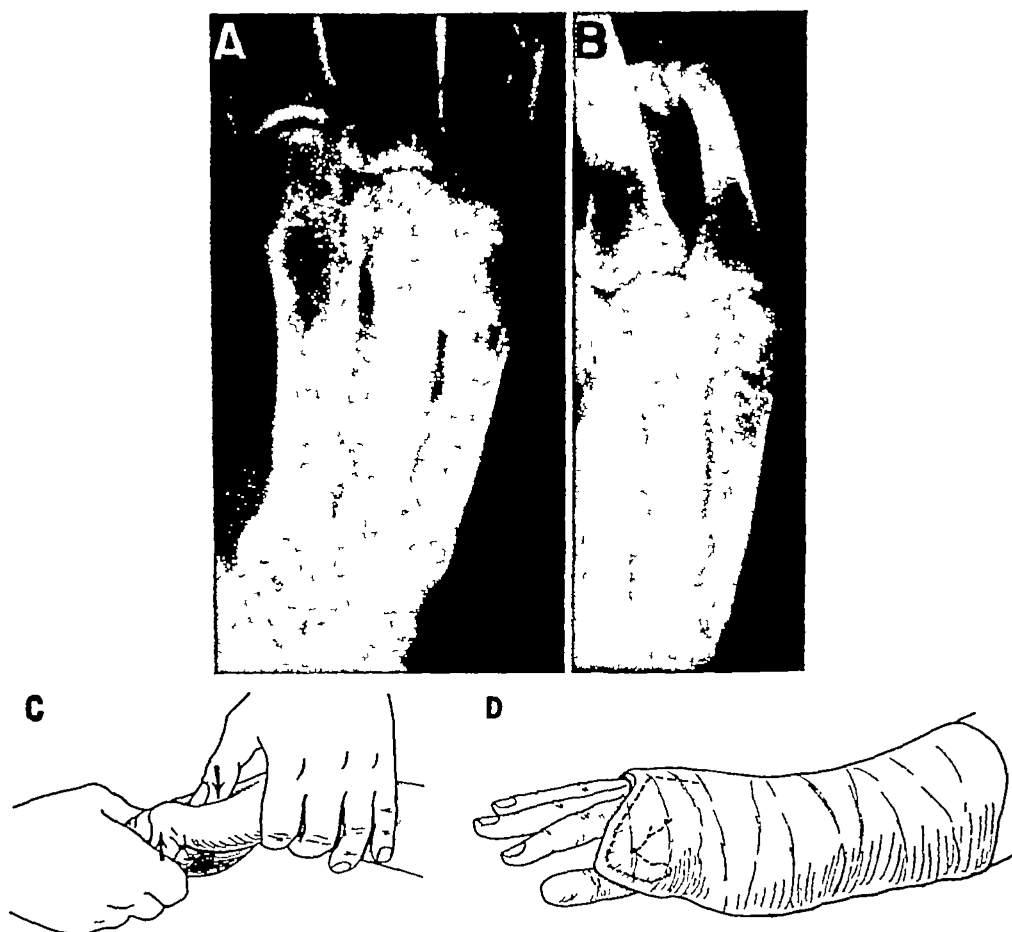


FIG 140 —*A*, "punch fracture" of fifth metacarpal, *B*, after reduction and three weeks' splinting *C*, method of reducing fracture arrows show direction of forces applied *D*, cast for this type of fracture

pressure is maintained to prevent the angulation from recurring while the cast is drying

This procedure can be accomplished nicely with local anesthesia and the patient need not remain in the hospital. A check-up x-ray should be taken The cast is left on for three weeks, during which time the uninvolved fingers should be actively exercised After the cast is removed there is difficulty in obtaining full extension of the proximal interpha-

langeal joint This is only temporary and responds best to active exercises, not to passive stretching

Another acceptable method of fixation is by a Kirschner wire driven up the medullary cavity (Fig 141, Plate 2, *B*) After reducing the fracture by the maneuver described above, the finger is held flexed about 45 degrees, and a Kirschner wire is drilled through the metacarpal head and up the medullary cavity into the base The pin is cut off short, the end pushed under the skin and a splint applied as in Figure 151 The pin is removed, with local anesthesia, about three weeks later A short forearm cast with finger extension is used with this method

Open Fractures

Because the metacarpals are subcutaneous posteriorly, open fractures are not uncommon Unless there is a definite avulsion of the soft tissues it is usually possible to reduce the fracture, close the skin and obtain a good result These patients should be hospitalized and given antibiotic therapy Debridement of the wound should be done with a major surgical setup and viable or useful bone fragments should not be removed Internal fixation of the fracture may be necessary and is accomplished either by applying a small Sherman plate, by drilling the fragments and fastening them together with a wire loop (Fig 142) or by pinning with an intramedullary wire (Fig 141, Plate 2, *A*) Because this type of injury is usually from a blunt instrument, the extensor tendons as a rule escape injury If the extensor tendons are severed and the wound is not too dirty or the time interval too great, the tendons can sometimes be repaired and primary healing obtained However, since the repaired tendons must be relaxed by keeping the wrist and fingers straight, some joint stiffness is apt to follow

In open fractures of the metacarpal shafts nonunion is common because of stiffening of the metacarpophalangeal joint in extension After the cast is removed, the patient in attempting to flex the finger bends the metacarpal at the fracture site instead of at the joints For this reason it is much better to use internal fixation and then to splint the wrist in extension, extending the cast no farther than the palmar crease to allow flexing of the fingers If necessary, the dorsal plaster splint may be extended beyond the metacarpal heads and brought over the proximal phalanges to maintain flexion of these joints, or pulp traction may be used through the finger pads to maintain flexion during the first few days The rubber bands

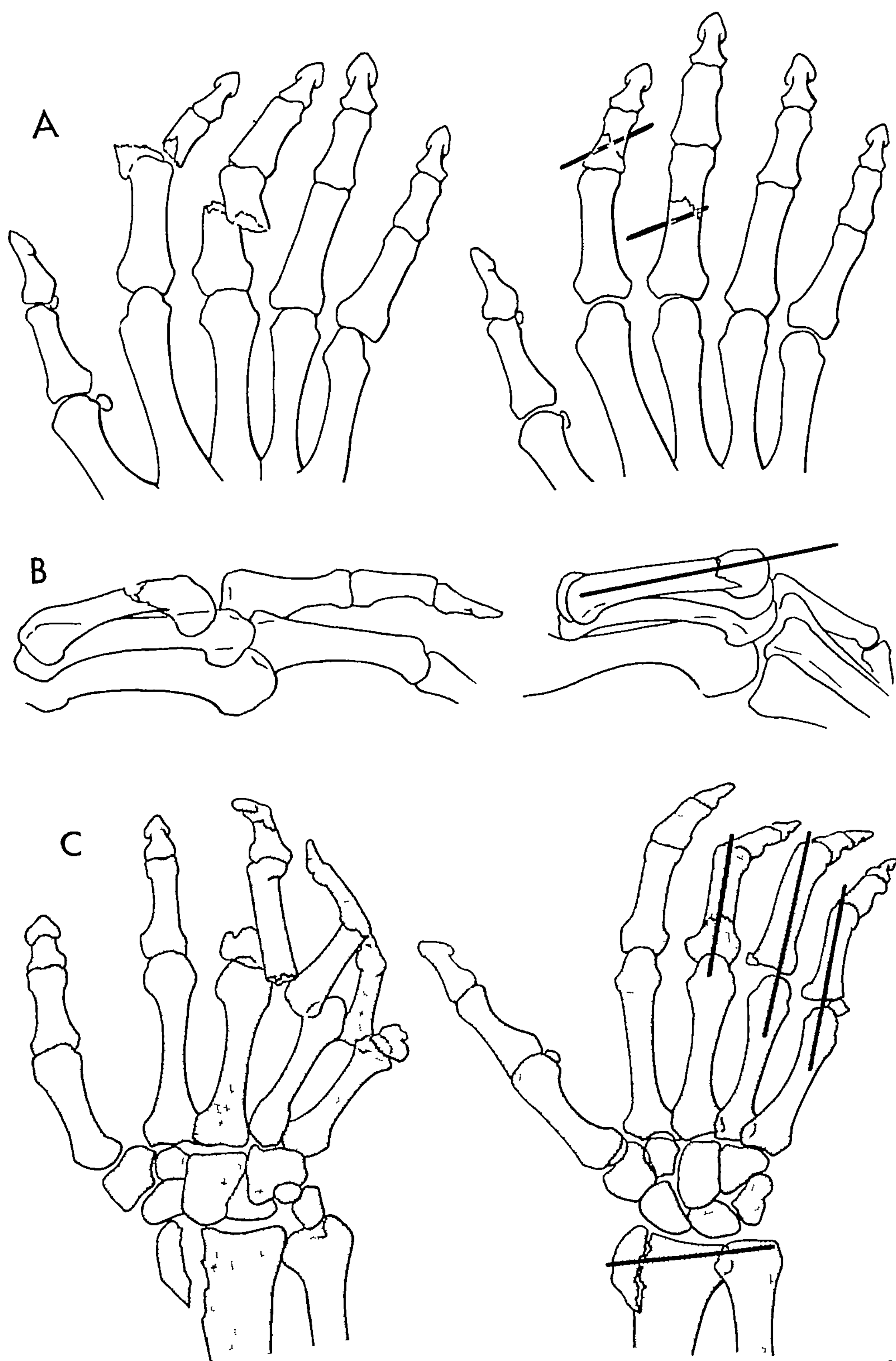


FIG 141, PLATE 1—Examples of cases in which Kirschner wire pinning is indicated (drawn from actual cases) *A*, open fractures of phalanges, *B*, severe punch fracture, *C*, crushing injury of hand with multiple fracture dislocations

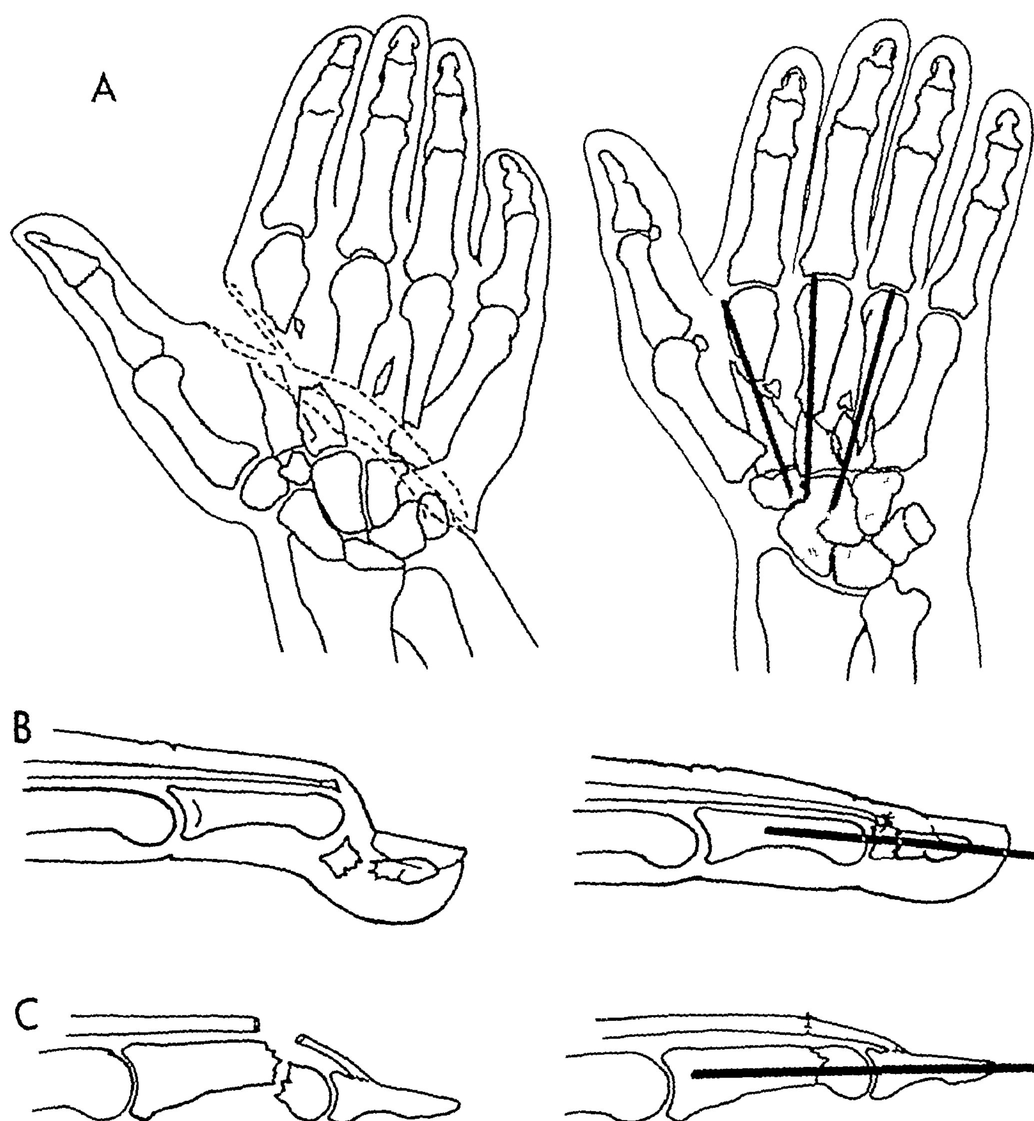


FIG 141, PLATE 2—Examples of cases in which Kirschner wire pinning is indicated *A*, sawmill injury with marked loss of bone and soft tissue, *B*, fracture of distal phalanx with rupture of extensor tendon resulting in displacement of fragments, *C*, unstable fracture of middle phalanx near condyles with tendon severed

used for traction should be removed each day and the fingers exercised to prevent joint stiffness As in any other fracture of the hand, the uninjured fingers should be exercised daily

Mason and Allen treat open fractures by economical debridement, wound closure, using skin grafts if necessary, and compression dressings,

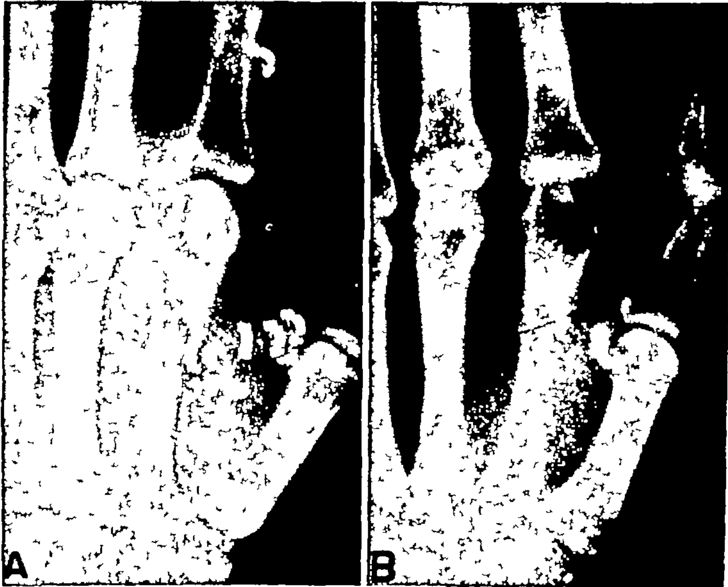


FIG 142—Open fracture of metacarpal with wide separation of fragments *A*, nonunion after one month's immobilization, *B*, solid union after internal fixation with circumferential wire

with the hand held in the position of function with the universal hand splint (see Fig 21, *B*) The bone fragments are manipulated into place over the padded splint and held by a combination of position and compression without traction Nerves and extensor tendons may be repaired with this method but flexor tendons should be left alone

NONUNION

If the proper primary treatment of an injured metacarpal is carried out, nonunion should be rare unless there is actual loss of bone The commonest causes of nonunion are failure to reduce the fracture, excessive traction and the use of forcible manipulation after allowing the metacarpophalangeal joints to stiffen (Fig 143) In nonunion or delayed union the fracture continues to angulate after the splinting is removed,

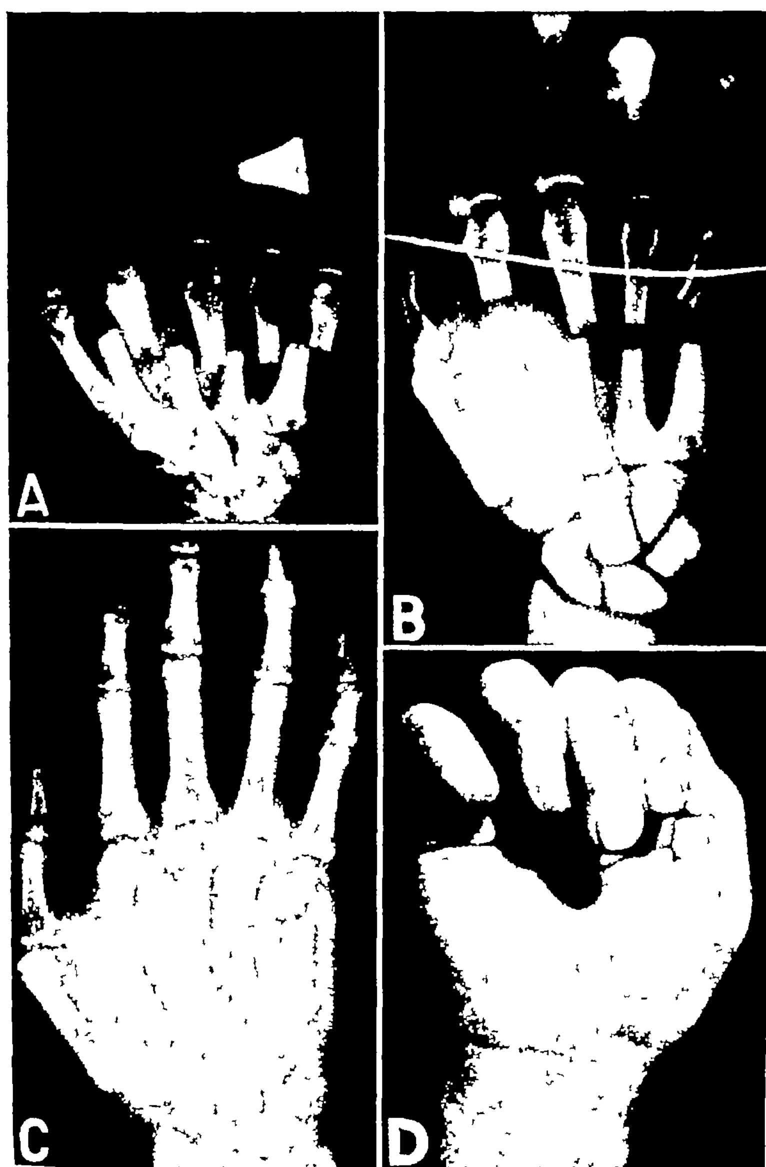


FIG 143 —*A*, fracture of all metacarpals from press injury Primary treatment elsewhere by skeletal traction through metacarpal heads *B*, too much traction, *C*, nonunion, and *D*, stiffness of all metacarpophalangeal joints Grip extremely weak Bone grafted with eventual good result (see Fig 200)

and pain in the fracture site and limitation of joint motion continue If allowed to persist, a certain degree of clawhand may be produced To correct this condition requires a combined operation of bone grafting and capsulectomy of the metacarpophalangeal joint A description of bone grafting will be found in Chapter 14

Fracture of the Thumb Metacarpal

(Bennett's Fracture)

Fractures of the base of the metacarpal of the thumb are exceedingly common, whereas fractures of the shaft and head are uncommon Because this bone is relatively heavy throughout its shaft, fracture of the neck, so common in the metacarpal of the little finger, does not occur

Pathology —Two types of fractures of the base of the metacarpal occur In one the fracture line runs through the junction of the base and the shaft This fracture is usually transverse and its treatment is simple More often, the fracture runs through the hook on the anterior surface of the proximal articulating end of the metacarpal, producing Bennett's fracture which is actually a fracture-dislocation (Fig 144) The long abductor of the thumb draws the shaft and attached articulating surface proximally and the small fragment, consisting of the hook and part of the joint surface, remains held to the carpometacarpal joint by the capsular ligaments A combination of these types is sometimes seen in which the base is fractured away from the shaft and also split (Fig 145)

Diagnosis —The history of an injury from a punch or fall or a violent wrench such as takes place in motorcycle accidents and skiing injuries, together with pain and tenderness at the base of the metacarpal and loss of power and motion of the thumb, is an indication for x-rays Frequently, shortening of the thumb occurs and the deformity is grossly visible

Treatment —Any fracture in this location where redisplacement will follow simple reduction requires traction General anesthesia is advisable Reduction is obtained by a combination of traction on the thumb and abduction of the metacarpal with pressure over the proximal end of the shaft A close-fitting plaster cast is then applied with the wrist in extension and slight radial deviation The cast should be well molded around the anterior surface of the thenar eminence A traction pin is inserted in the thumb, and rubber-band traction made to an outrigger on the cast at an angle of about 60 degrees abduction Hyperextending of the metacarpo-

phalangeal joint while allowing the metacarpal to flex is bad In double-jointed individuals hyperextension of the thumb may produce crippling of this joint To avoid hyperextension, Bunnell passes the traction pin through the distal end of the metacarpal For most cases this is not necessary and gives no better alignment than the classic method of making pulp traction on the distal phalanx or skin traction on both phalanges Traction in abduction must be maintained for three to four weeks and



FIG 144 *(left)* —Typical Bennett's fracture Treatment by traction and abduction gave good result.

FIG 145 *(right)* —Comminuted Bennett's fracture treated by traction with fair result

x-rays taken at intervals Adhesive strapping is applied to the thenar region for another two weeks

C J Wagner's method of treatment utilizes a transfixion pin The hand is prepared as for a surgical operation and the patient anesthetized. The fracture-dislocation is reduced by a combination of traction, abduction and pressure over the proximal end of the metacarpal The assistant then inserts a Kirschner pin directly through the base of the metacarpal and into the greater multangular (Fig 146). An x-ray is taken to confirm the reduction and the position of the wire. The wire is then bent at a right angle, cut off and buried deeply beneath the skin The hand and thumb

are incorporated in a cast which should leave the fingers and the distal joint of the thumb free to move The cast is left on for four weeks, it is then removed, x-rays taken and the pin removed Some supplementary support is applied for two weeks Wagner believes that this method is suitable for all fractures which can be treated by closed reduction In old cases requiring open reduction the results were poor In these and in comminuted fractures with widespread involvement of the articular surfaces he recommends arthrodesis of the metacarpal-greater multangular joint

Open reduction is used for fractures of the hook of the thumb metacarpal which cannot be held reduced by manipulation and traction. To hold the fracture fragments in place Bunnell uses three steel pins Expo-

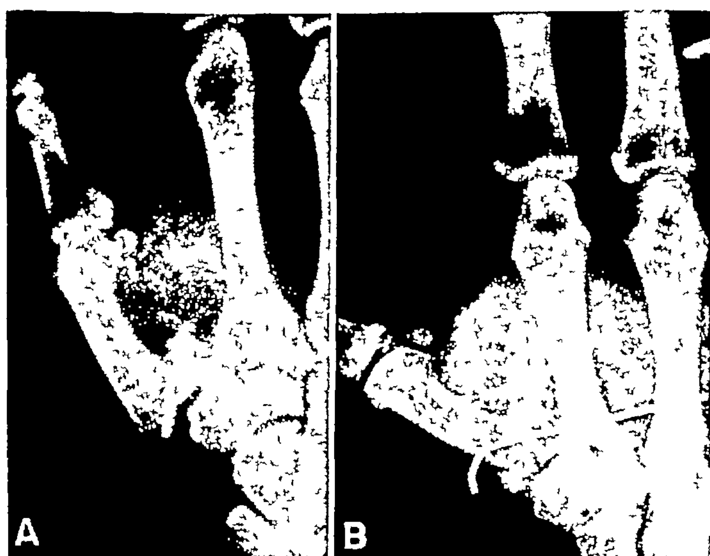


FIG 146 —*A*, comminuted Bennett's fracture, *B*, after Wagner's method of treatment.

sure is obtained by incision along the dorsum of the metacarpal and the flexion crease of the wrist The muscles attached to the metacarpal are stripped off toward the palm of the hand and later replaced The fracture fragment is held in place by two pins, and a third pin inserted through the greater multangular and metacarpal prevents redislocation The pins are later withdrawn Prolonged immobilization is necessary to prevent redisplacement when such an open operation is done

In oblique fractures near the base in which reduction is difficult to maintain, an open reduction may be elected The fracture fragments are fastened together by a loop of wire passed through drill holes in the posterior cortex§ A short incision is made parallel to the metacarpal and the

§ The author prefers this method whenever accurate reduction is difficult to maintain

long abductor tendon, and the posterior surface of the bone is exposed subperiosteally, retracting the radial nerve and extensor tendons Appropriate drill holes are made and a loop of no 22 wire passed through and twisted The usual thumb abduction cast is applied

Simple transverse fractures through the base of the thumb metacarpal, like the simple fractures through the base of any other metacarpal, require only replacement of the fragments and immobilization for about three weeks in abduction in a cast Minor degrees of displacement need not be corrected provided the joint surfaces are not seriously disturbed

The principles underlying the treatment of fractures of the shaft and head of the thumb metacarpal are identical with those for the other metacarpals

Metacarpal Dislocations

Carpometacarpal dislocations—The most common carpometacarpal dislocation is the sprain or stave fracture just described under Bennett's fracture Occasionally there is dislocation without a fracture Even though no fracture is present, traction in the abducted position after reduction should be used to prevent redislocation

Dislocation of the second to the fifth carpometacarpal joints is relatively uncommon and when it does occur the four bones are usually dislocated en masse This type of injury is produced in automobile or motorcycle accidents when violent pressure is made on the palm of the hand grasping the wheel (Fig 147) There are also isolated dislocations of the base of one metacarpal from its carpal bone (Fig 137) Because of the arching structure of the carpus, the only direction in which this dislocation can occur is posteriorly Such injuries result when the hand is caught in the grip of machinery exerting direct pressure, such as a hay baler or punch press The dislocation is easily recognized by the prominence of the proximal end of the dislocated bone on the dorsum of the wrist

In recent cases no difficulty is encountered in reduction General anesthesia is necessary, and a combination of traction on the finger or fingers and direct pressure over the base of the metacarpals will effect reduction When the wound is compounded a similar maneuver is carried out and a few sutures then passed through the capsule and the periosteum or the posterior surface of the joint to prevent redislocation The hand should be immobilized with the wrist in a neutral position, plaster splints being applied with a minimum of padding and the fingers allowed to move freely At least three weeks' immobilization is necessary

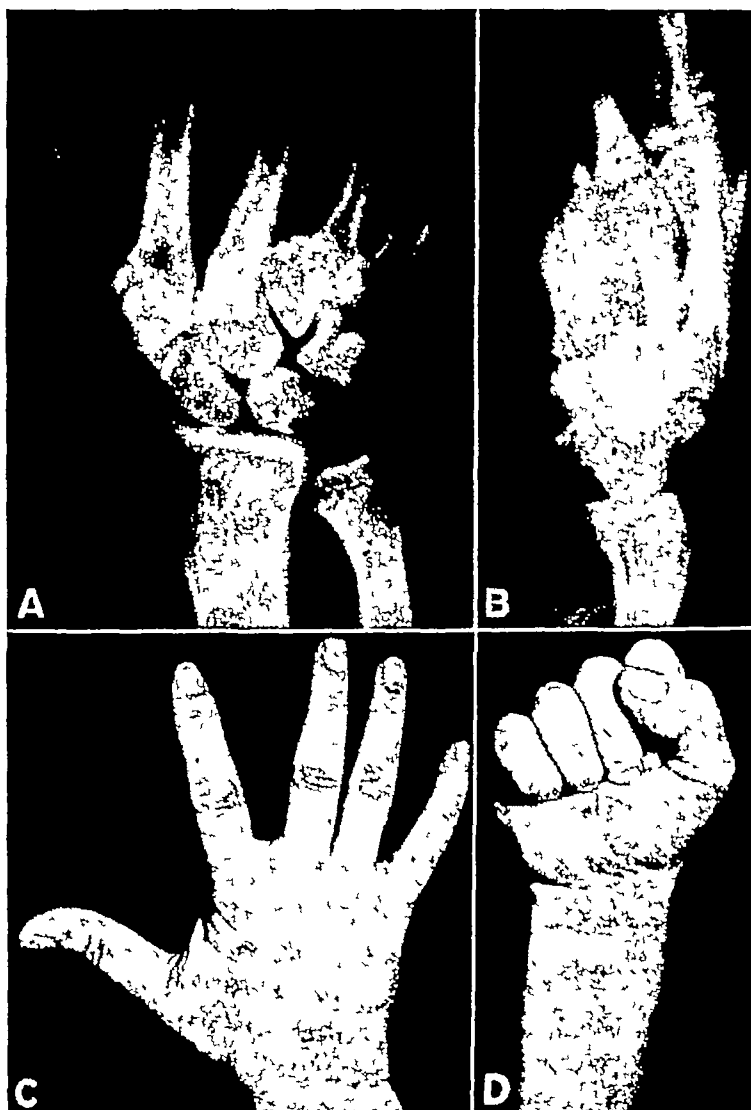


FIG 147 —*A* and *B*, complete posterior dislocation of second to fifth carpometacarpal joints treated by manipulative reduction and immobilization for one month *C* and *D*, result.

METACARPOPHALANGEAL DISLOCATIONS —*Thumb.*—Forcible hyperextension of the thumb produces this dislocation Usually the phalanx is displaced backward on the metacarpal head, but the phalanx may also be dislocated forward or laterally The lateral ligaments of the joint capsule are torn and the head of the metacarpal is driven forward through a slit in the capsule, at times the tendons of the long and short flexors are interposed between the articular surfaces Diagnosis is fairly simple the proximal phalanx of the thumb is held in the position of hyperextension, the

distal phalanx is flexed and the metacarpal is adducted The position is similar to that of a "double-jointed" thumb

With the knoblike end of the metacarpal driven through the joint capsule, reduction by simple traction will rarely be successful Under general anesthesia, a combination of hyperextension, traction and pressure will usually reduce the dislocation The proximal phalanx of the thumb is grasped, using an adhesive bandage if necessary, and traction and hyperextension made with one hand while the base of the phalanx is pushed forward on the metacarpal with the other hand (Fig 148). When the base of the phalanx is brought over the end of the metacarpal the joint is slowly flexed; if reduction is satisfactory, normal flexion can be obtained This maneuver requires considerable force but should not be done by jerking After reduction, the joint should be held in a slightly flexed position and immobilized for three weeks either with adhesive strapping and a splint or with plaster of paris The joint should be protected against forcible hyperextension for four more weeks by means of adhesive strapping

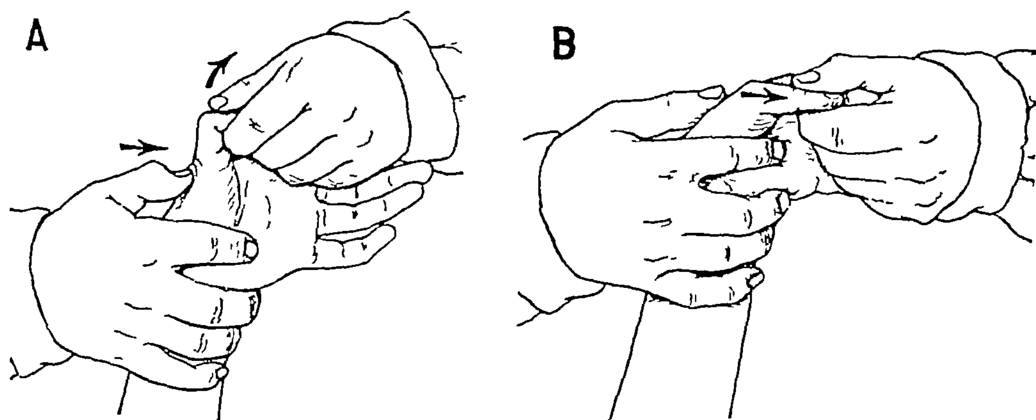


FIG 148—Reduction of dislocation of metacarpophalangeal joint of thumb *A*, with traction and extension made on the proximal phalanx, the base of the phalanx is pressed forward over the head of the metacarpal *B*, continued traction is made on metacarpophalangeal joint during flexion

Whenever closed reduction fails, an open reduction is necessary (Fig 149) A dorsolateral incision about 1½ in long gives adequate exposure and good visualization of the interposed tendons and the constricting capsule The rent in the capsule is widened so that the metacarpal head can be extricated, and the dislocated bones are then easily replaced. The postoperative management is the same as that following a closed reduction

Other metacarpophalangeal joints—These dislocations are due to forci-

ble hyperextension or occasionally to hyperflexion The joint capsule is torn, the metacarpal head projects through and the base of the phalanx rests on the neck of the metacarpal Compounding may be present The index and fifth fingers are more easily dislocated than the middle two

Reduction may be carried out under local anesthesia, although general anesthesia is preferred In simple cases, moderate traction on the finger may be all that is necessary Posterior dislocations require a maneuver similar to that described for the thumb, the finger being hyperextended with traction and the base of the phalanx pressed forward into its proper position on the metacarpal head In anterior dislocations a reverse maneu-



FIG 149—Posterior dislocation of metacarpophalangeal joint of thumb with interposed tendon requiring open reduction

ver is carried out, the finger is flexed, and pressure is applied over the anterior surface Following reduction, the joint should be immobilized with a curved metal gutter splint for about two weeks The joint is splinted in moderate flexion to prevent permanent stiffness

Fresh dislocations do not require open reduction but those that are seen rather late will Reduction may be done under local anesthesia, preferably through a dorsolateral or midlateral incision After enlargement of the slit in the joint capsule and retraction of the tendons which may be interposed, reduction is quite simple

Compound dislocations of metacarpophalangeal joints not infrequently are a result of open wounds Their treatment is described fully in Chapter

9 (Fig 93) Another type of dislocation occurs in crushing injuries in which the joint capsule is torn so badly that redislocation occurs immediately after reduction In these cases the metacarpal head and proximal phalangeal joint surfaces can be maintained in opposition by transfixion with a Kirschner wire (Fig 141, Plate 1, *C*)

INTERPHALANGEAL DISLOCATIONS—These are rather common injuries in football and baseball games, falls, fights, etc, and are often treated by the nearest bystander The distal phalanx is usually displaced backward or laterally over the proximal one (Fig 150) There is an

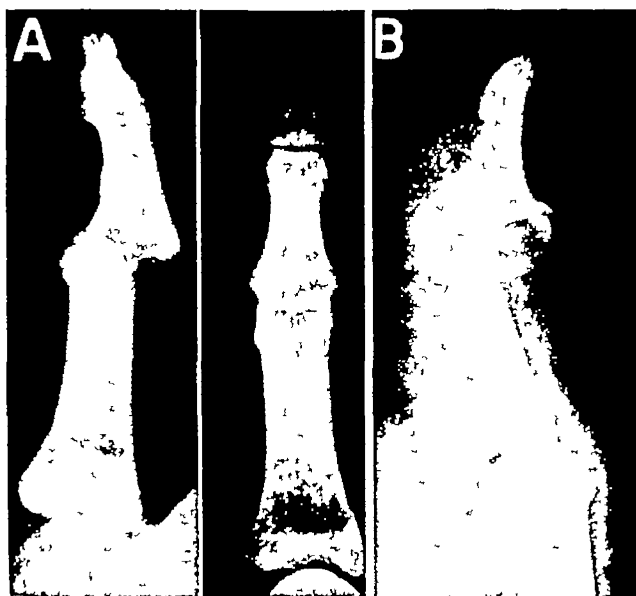


FIG 150—*A*, lateral dislocation of proximal interphalangeal joint of long finger Manipulative reduction and one week's immobilization gave good result. *B*, posterior interphalangeal dislocation of thumb, treatment by manipulative reduction and one week's splinting With extensive osteoarthritis already present, joint became quite stiff

associated tearing of the lateral ligament of the joint capsule, and within a short time pronounced swelling may obscure the dislocation Compound dislocations are not at all uncommon In such injuries the tendon is usually exposed in the anterior wound which is at the flexion crease of the finger Since many of these dislocations are actually fracture-dislocations, an x-ray should be taken even if the dislocation has already been reduced

Skill rather than strength is needed for reduction, the principle being to disengage the bone ends from their abnormal position and slide them back into place Traction with pressure over the base of the distal phalanx in the line of reduction, followed by flexion of the joint will result in re

duction whether the dislocation is posterior or lateral After reduction an x-ray should again be taken to make certain everything is all right A palmar splint which holds the joints slightly flexed is left on for about 10 days and then removed and active exercises begun

A few cases require open reduction In compound injuries a surgical approach through a different area may be advisable A midlateral or dorsolateral incision is usually satisfactory, and if a traumatic wound is present it is separately excised and closed

The use of anesthesia is largely a matter of individual preference If the patient is seen early, no anesthesia or local anesthesia may be used for the simple cases After pronounced swelling has appeared or when open reduction is necessary, general anesthesia is usually desirable

Fractures of the Phalanges

The common fractures of the phalanges of the fingers and thumb are often poorly treated Dismissing them as minor injuries may result in considerable disability These fractures are similar to any long bone fracture, but in addition there may be complicating injuries of the adjacent tendons if displacement occurs This is particularly true when there is extensive comminution or an open wound

Displacement in the proximal phalanges produces angulation of the fragments toward the palm, since the intrinsic muscles flex the proximal fragment while the long tendons simply add to the displacement by causing shortening with a buckling force The only exception is in the rare fracture at the proximal end of the middle phalanx Here the long extensor tendon pulls the proximal fragment dorsally while the flexor tendons pull the distal fragment ventrally, producing dorsal angulation at the fracture In the distal phalanx displacement is usually the result of the force causing the fracture and not the pull of the tendons The one exception to this arises when the extensor aponeurosis is torn loose at the same time that the neck of the distal phalanx is fractured The pull of the unopposed profundus tendon will then produce volar angulation at the fracture

Diagnosis is obvious when deformity is present or there is false motion accompanied by other signs of fracture, such as swelling and pain Many cases, however, result from direct violence and do not show the usual signs of fracture In these and in any crushing injury, examination is not complete without an x-ray The amount of disability resulting from frac-

tures which are overlooked is out of all proportion to the apparently mild trauma which may cause such an injury

TREATMENT—The fundamental principle in treatment of phalangeal fractures is to bring the distal fragment into alignment with the proximal fragment, maintaining reduction by relaxing the muscle pull which tends to produce the displacement

UNDISPLACED FRACTURES—Because the pull of the short muscles of the hand or of the long tendons is very powerful, even undisplaced fractures should be splinted in a position which tends to relax this pull. The

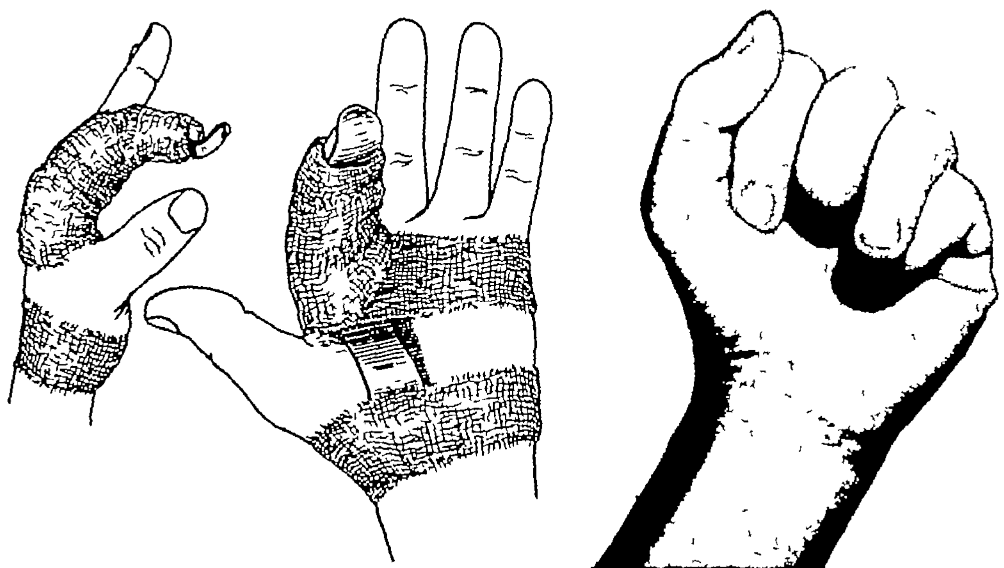


FIG 151 (*left*) —Splinting for average, undisplaced fracture of proximal or middle phalanx (For splint used, see Fig 20, *A*)
FIG 152 (*right*) —This apparently undisplaced fracture was splinted on a tongue blade, healing with rotation caused finger to cross on flexion

finger should be immobilized with a curved metal gutter splint strapped to the palm and to the segments of the finger with adhesive, each joint being allowed to flex about 45 degrees (Fig 151) This splint is worn about three weeks, during which time the other fingers and the thumb are routinely exercised Fastening of the finger to a straight tongue-blade splint is not advised (Fig 152) In fracture of the shaft of the proximal phalanx of the thumb without displacement, immobilization in the flexed position is also indicated The malleable metal gutter splint is bent and twisted to fit along the front of the thumb and the thenar eminence and fastened into place with Elastoplast

DISPLACED FRACTURES—In fractures of the *proximal phalanx,* displacement is toward the palm due to the pull of the lumbricales and

interossei. Reduction by a combination of traction and flexion may be carried out with either local or general anesthesia Some of these fractures become *stable* after reduction and can then be immobilized with the curved metal splint used for undisplaced fractures (Fig. 153) In *unstable* fractures the operator must decide whether to use traction or operative intervention As each case presents its own problem, no hard and fast rule governs this choice Usually, comminution suggests the use of traction and short oblique fractures require internal fixation The technics of internal fixation are discussed under the treatment of open fractures (p

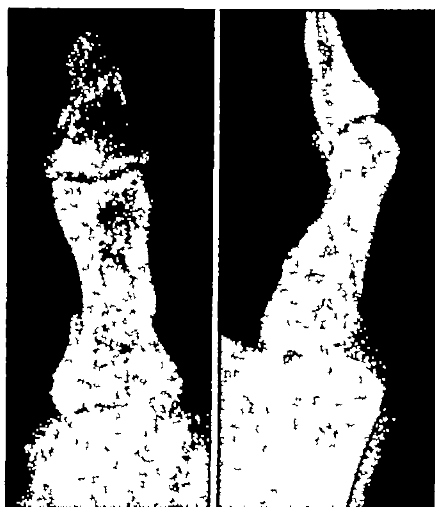


FIG 153 —Comminuted fracture of proximal phalanx of thumb Manipulative reduction and splinting in flexion for three weeks gave good result

302) In unstable fractures, whether comminuted or not, continuous traction must be applied unless internal fixation is used

Traction is made by an outrigger on a closely fitting plaster cast. The cast is applied to the forearm and wrist with the wrist cocked up, and the splint to hold the finger is made of wire of about the same size and strength as a wire coat hanger This is bent to fit the plaster cast proximally and is shaped to fit the finger when the finger is flexed (Fig 139), avoiding pressure where the finger fits over the splint To prevent rotation of the fracture fragments, it should be remembered that the flexed fingers do not parallel each other but should all point toward the tubercle of the navicular The splint is then incorporated in the partly dry cast

It is the positioning of the fracture fragments rather than the traction which maintains reduction Usually, the metacarpophalangeal joint will

need to be flexed to about 45 degrees, the proximal interphalangeal joint to 60 degrees and the distal interphalangeal joint to about 45 degrees At times 45 degrees of flexion at the metacarpophalangeal joint will not be adequate It is wrong to have the splint angulated at the fracture because there will be damage to the soft tissues and tendons on the front of the finger

The most reliable and safest type of traction is that applied by a pin passed through the pulp of the distal segment of the finger. Local anesthesia may be used for this procedure, an injection being made in the skin on one side of the finger and the needle passed through the finger, injecting a few drops along the way and in the skin on the opposite side The proper location of the traction pin is about midway along the nail, just anterior to the midpart of the cancellous tuft in the dense fibrous tissue attaching the finger pad to the tuft It is not desirable to pass the pin through the bone or through the soft fatty pad where scarring will result, and under no circumstances should the pin be placed more proximally on the flexor surface where it will communicate with the flexor tendon sheath. After reduction, elastic traction is made to the pin from the outrigger on the front of the wrist

Palpation of the bone fragments during reduction gives a fair idea of their position X-rays following reduction are essential Reduction under the fluoroscope is not advisable because of the ever present possibility of a burn

With good reduction, union will usually be secured in three to four weeks in fractures which are not compounded Nonunion may follow excessive traction or faulty reduction The uninvolved fingers should not be immobilized After the splint is removed, the finger should be actively exercised but forcible manipulation avoided

In fractures of the *middle phalanx* the commonest displacement is a volar angulation The technic of reduction and immobilization is exactly the same as that described for fractures of the proximal phalanx (Fig 139) The only exception is in immobilization of a fracture between the insertions of the extensor tendon and the flexor sublimis tendon at the proximal end of the shaft This fracture should be splinted with all the joints of the finger in extension, and it is one of the few fractures of the phalangeal shafts that is properly immobilized in this position

In fractures of the *distal phalanges* comminution from crushing with associated injury of the soft parts is the rule, and subungual hematomas and hematomas of the anterior closed space are usually present Most closed fractures will heal without difficulty in about two weeks if simple

splinting is applied, open fractures require longer immobilization (Fig 154) Evacuation of a hematoma under the nail often makes the patient more comfortable

The best form of splint is the simple four-pronged finger guard (Fig 20, *C*) A little gauze is wrapped around the finger to give padding and the guard is bent to fit the finger and fastened on with adhesive Soaking the fingers in hot water and failure to immobilize them will result in increased pain due to further bleeding On the other hand, proper protection and splinting of the fingers will make the patient much more comfortable

Follow-up x-rays—Redisplacement is a very common cause of mal-



FIG 154—*A*, open fracture of distal phalanx with wide separation of fragments Immobilization for two months resulted in eventual fibrous union, *B*, and good function

union in all fractures and is especially likely in finger fractures Patients often bump and bend their splints, overuse their hands, and are generally indifferent about after-care unless closely followed For this reason a follow-up x-ray *a few days* after reduction as well as the immediate post-operative x-ray is often advisable At the slightest sign of redisplacement the surgeon should readjust the splints—traction or otherwise—and caution the patient about his actions

OPEN FRACTURES—In older textbooks the usual recommendation was that open fractures of the fingers be treated by amputation Many patients would have less permanent disability if this method were still followed To obtain reduction and union of these fractures and to avoid local stiff-

ness accompanied by stiffness of the rest of the hand taxes the skill of the most expert operator Amputation is now the treatment of choice only if there are complicating vascular injuries or severe comminution with injuries to tendons and joints Injury to more than one finger makes amputation less desirable The finger is less apt to require amputation in injuries caused by sharp instruments, such as an axe, fan blade or saw, than in crushing injuries If one good skin flap which contains a digital



FIG 155—Unstable open fracture of proximal phalanx with wide displacement of fragments treated by internal fixation with good result

artery and nerve is intact, the finger can often be saved and restored to usefulness On the other hand, when the fingers have been crushed by a rolling mill or by being caught between a cable and a pulley, under a log or in a press, the tendons will be intact but the soft tissues are burst open, often with avulsion of the nerves and destruction of the blood supply (see Fig 42, *A*)

In the less severe types of open fractures, in which the bone is displaced but there are no complicating vascular or tendon injuries, reduction may be secured, although it is difficult to maintain by simple methods

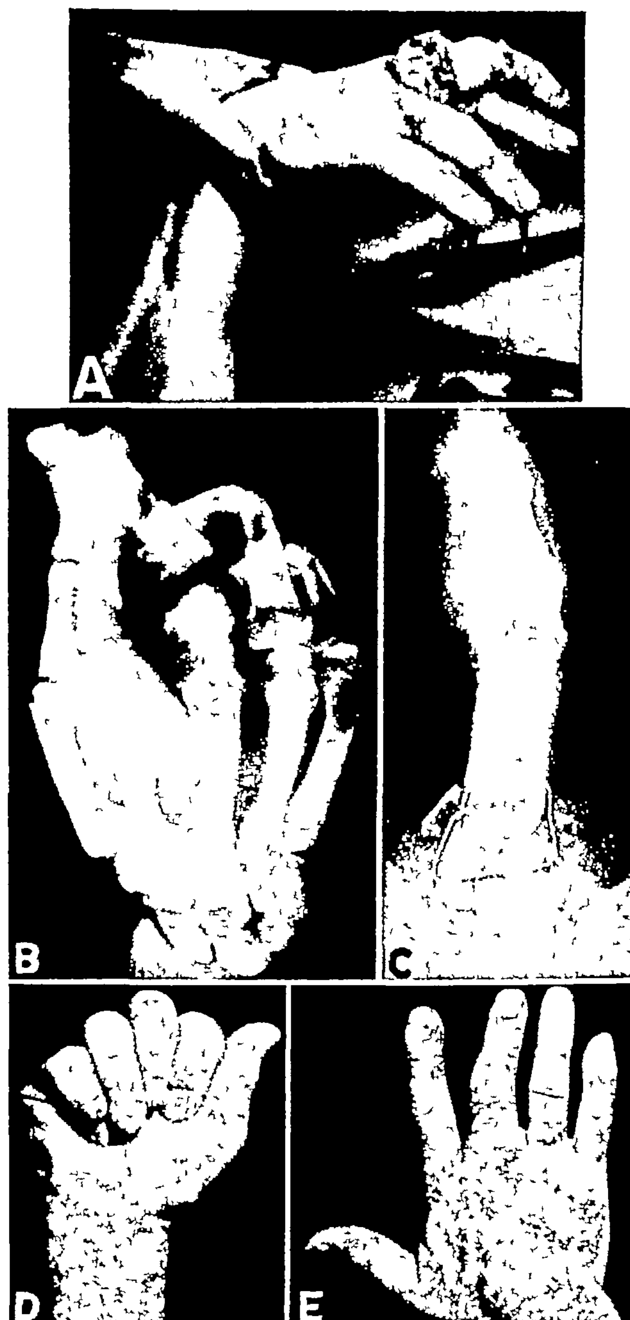


FIG 156 —*A,* finger almost cut off by ventilating fan, open fracture and tendon and nerve injury *B,* original x-ray *C,* after treatment by immediate open reduction and internal fixation with wire *D* and *E,* end result, showing good function despite slight angulation at fracture site due to loss of bone

For treatment, an operating room setup with general anesthesia is needed, and the whole hand should be prepared as for any major operation The wound should be carefully debrided and any devitalized tissue and foreign bodies removed Loose fragments of bone, as a rule, should not be discarded unless they are completely detached from their blood supply and obviously contaminated The simplest method which will enable the surgeon to reduce the fracture and close the wound should be used If reduction by manipulation and traction can be maintained with the finger flexed, use of a splinting apparatus such as that described for closed fractures is recommended The principal pitfall is that the wound often lies against the splint in such a way that healing is seriously compromised In this circumstance and when reduction is not easily maintained, some form of internal fixation is advisable

For internal fixation, the bone is approached through the original wound or a midlateral incision The bone fragments are drilled and held in place with a wire loop or a small Sherman plate (Fig 155) Use of intramedullary Kirschner wires to hold the fracture in place often does not give stability Good alignment with adequate bone-to-bone apposition should be secured even if some shortening is produced If the mechanics of the finger are not upset, good function can be restored

A towel clip may be used to grasp the bone and manipulate it into place, and the bone may then be held by the fingers or the towel clip while being drilled and wired together (Fig 156) Splinting is much simplified when internal fixation is used, particularly if the fixation is rigid enough actually to hold the fracture fragments together The simplest possible repair of the soft parts should be done The extensor tendon, if divided, can be rejoined with a simple mattress suture of wire, if only partially divided, the ragged part should be trimmed away but not repaired Flexor tendons should not be repaired at the time the fracture is fixed because they will unite to the bone callus It is better to wait until the soft parts and the fracture have healed and at a second operation remove the internal fixation about the fracture site and insert a tendon graft

Open and unstable fractures of the proximal phalanx of the thumb are not encountered as often as finger fractures of the same type When they do occur it is even more important to secure union (Fig 157)

CRUSHING INJURIES —In severe injuries caused by direct crushing, the problem of treatment is one of attempting to reduce the fracture and repair the soft parts without compromising the circulation of the parts In treating some open fractures the bone fragments may be shortened with advantage This is indicated when the volar skin is badly damaged or

defective About ¼ in of bone can be removed without seriously impairing function (Fig 40) It may also be advisable to slit the flexor tendon sheath to prevent the flexor tendon from binding If all fingers are crushed, a primary amputation leaves the patient with an unapposed thumb and no prospects for reconstructive surgery. Therefore any available portion of a digit should be saved to give the patient at least a pincher If the proximal joints remain mobile, surprisingly good function is obtained even though what is left of the fingers is short and stiff When a line of demarcation develops after primary repair, it will usually be at the distal edge of the palm or farther out on the finger

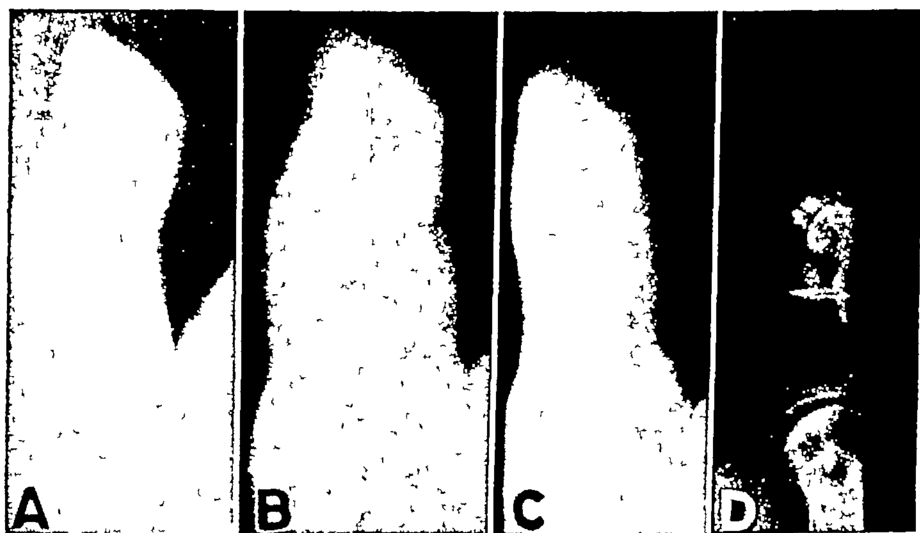


FIG 157 —Irreducible fracture of proximal phalanx of thumb in which tendon was caught by spicule of bone *A* and *B*, after attempted manipulative reduction, *C* and *D* result two months after open reduction and internal fixation

After the devitalized tissues are removed, the raw area can be covered by a flap or skin graft and some degree of function in pinching and grasping preserved This is better than a primary amputation at the metacarpophalangeal joints

For repair of these injuries the routine operating room setup is needed Circulation is so important and so precarious that it is better not to use a tourniquet Also, in tying bleeders, one should avoid inclusion of a main artery when only the branch needs ligation Debridement of the wound is carried out, followed by assessment of the damage In these injuries the palm is split wide open, the skin is avulsed from the back of the hand and the fingers are split from end to end The intrinsic muscles of the hand are in spasm, flexing the proximal fragments of the phalanges to a maximal

degree Reduction of the fracture which can only be secured by bringing the distal fragments around into alignment with the proximal fragments causes a bunching up of the soft tissues in the distal palm and interferes with venous return Often a compromise must be made between securing good reduction and interfering with circulation As the interphalangeal joints will almost inevitably be stiff after such injuries, some malalignment may be allowed if the return circulation is impeded by overflexion of the fingers The fingers can be dressed over a cylindrical splint, such as the plunger of a 20 cc glass syringe (Fig 158). Mason and Allen have obtained satisfactory results in these cases by reducing the fracture, closing the wound and dressing the hand with compression on a position-of-function splint

The problem of maintaining reduction is greatly simplified if it is possible to apply internal fixation either by drilling the bone and passing a wire loop through the fragments or by applying a small Sherman plate or by pinning with Kirschner wires (Fig 141, Plate 1, *A*) The hand can then be dressed with the metacarpophalangeal and interphalangeal joints only moderately flexed Intramedullary pinning is not without danger owing to the possibility of infection and the proximity to the tendons Its principal indication is probably for comminuted fractures that cannot be otherwise managed

In wound closure, only the skin should be sutured, using a minimal amount of no 36 or 38 stainless steel wire So much tissue is damaged that it may be impossible to close the wounds completely, especially on the dorsum Since it is more important to close the palm than the dorsum, the palm is sutured and, if necessary, the wound on the dorsum is allowed to gape or is covered with a skin graft. When tying the sutures the operator should watch for blanching of the tissues, if it occurs, the stitch should be removed and a looser one used even if slight gaping results.

Drains are usually not necessary. A thin layer of petrolatum gauze should be applied next to the suture line followed by voluminous pressure dressings and splints to include the forearm, hand and fingers. The position of function is maintained

Postoperatively, the hand is elevated as high as possible and antibiotics given routinely Whenever there is much concern about circulation, anticoagulants, including heparin and dicumarol, may be given if laboratory facilities are available to determine the prothrombin time The initial dressing should be postponed as long as possible up to two weeks, at which time sutures may be removed, devitalized skin tags excised and further skin grafting carried out if necessary. X-rays are valuable at this

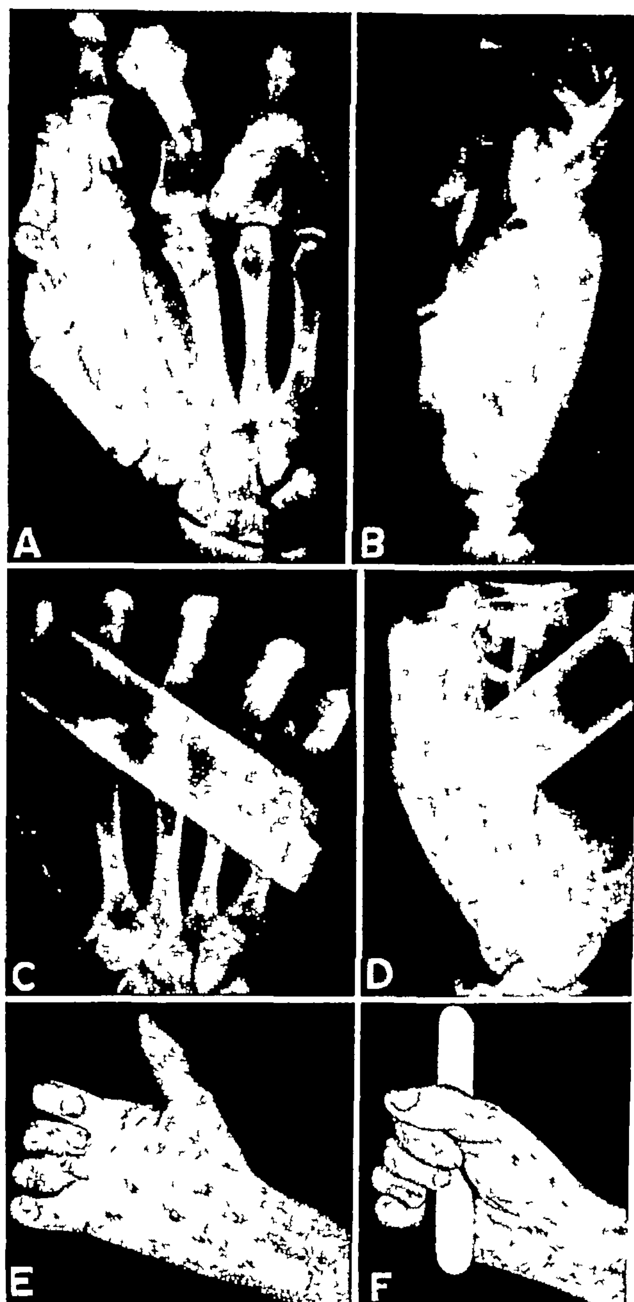


FIG 158 —*A* and *B*, open fracture of proximal phalanges of all digits (hand caught in steel straightener) Distal palm and digits were all burst wide open *C* and *D*, after immediate debridement and reduction with closure of wounds and immobilization in position of function Later, traction was applied and internal fixation used on thumb Portions of fingers and flexor tendon sloughed and contracture developed, final treatment consisted of resection of interphalangeal joints and arthrodesis of shortened fingers in position of function. *E* and *F*, result six months later

time but movement of the fracture site should be avoided while they are being taken So little callus may be visible in the x-rays that it is necessary to depend on clinical signs of union At the earliest possible time splinting should be removed and active motions instituted This sometimes may be done at the end of three or four weeks Some type of protective dressings should then be worn at night until the union is solid

RESULTS—In the simpler types of finger fractures the hand should be restored to normal function Even with open fractures which are displaced, almost normal function can be obtained if a good reduction is secured and kindly healing takes place and if stiffness of the joints can be prevented Usually a mild degree of flexion contraction of the interphalangeal joints will occur, particularly if the patient is past middle age This is not incompatible with good function if the metacarpophalangeal joints have a normal range of motion If these important joints can be preserved, grasp and pinch can be obtained even though the interphalangeal joints are quite stiff In extremely severe cases the surgeon will have to be content with such a result

SPRAINS AND SPRAIN FRACTURES

WRIST—This condition probably occurs more often than all other carpal injuries The wrist may be sprained in falls, automobile accidents, various athletic pursuits, etc Immediately after the injury, usually with hyperextension or occasionally with torsion of the wrist, there are severe pain and soreness Weakness in the hand persists and there may be moderate swelling Frequently, tenderness about the radiocarpal joint is present, this may be localized over the ligaments or may be in the snuffbox region or the carpus generally The usual x-rays in three views are necessary to rule out fracture

Treatment by immobilization of the joint in the position of function does much to shorten convalescence and relieve pain The best form of immobilization is a snug-fitting, thinly padded plaster cast extending from the upper forearm to the palmar crease (see Fig 23) In milder sprains, the wrist may be strapped with adhesive or Elastoplast The strapping is put on as a basket weave, front and back, and extends from the base of the fingers to the lower third of the forearm Elastoplast is better than tape since it can be applied circularly and gives snug compression without constriction After immobilization for 10 days to two weeks, heat and massage may be of benefit Most sprains will heal in about a month, although soreness may sometimes persist for as long as six months, if it does x-rays may be indicated

THUMB—The metacarpophalangeal joint may become damaged by a twist or lateral pressure and occasionally by hyperextension The lateral ligaments are ruptured or the joint capsule torn, depending on the direction of the force Laxness of the ligaments can be tested for when the joint is held extended and moved laterally while the metacarpal is held stationary There are pain and swelling around the joint and weakness of pinch

To relax the ligaments, the thumb should be splinted in a slightly flexed position with a curved metal splint Healing takes place after about a month This is the one sprain in the hand that should always be splinted Slight stiffness is usual but not disabling, whereas a weak joint that subluxates constantly is a real nuisance

FINGERS—*Interphalangeal joints*—Sprains of the interphalangeal joints are common in athletic pursuits and from falls, fights and putting too much pressure on the digit The pathology varies from mild sprains and tears of the lateral ligaments and joint capsules to incomplete dislocations which have been spontaneously reduced Chip fractures of the rim of the proximal articulating surface of the adjacent phalanx are common

Whenever an injury of a joint causes swelling, pain and limitation of motion, an x-ray should be taken to rule out fracture In sprains, limitation and pain on motion accompany weakness, and involuntary splinting is carried out by the patient, the finger not being used in co-ordination with its mates Treatment should consist of immobilization, with the joint slightly flexed on the standard curved metal splint After a *few* days the splint is removed and hot applications used Active exercises are carried out as pain permits The splint is worn at night and during working hours to prevent further damage

After healing, sprains of the proximal interphalangeal joints commonly exhibit a fusiform enlargement and some stiffening The joint may remain permanently fusiform and some flexion contracture is common despite all attempts to prevent it In the distal interphalangeal joint, stiffness without pain or deformity is not disabling, but in the proximal interphalangeal joint it results in a grumbling patient Furlong of England believes that early motion is essential and makes the patient move the finger by connecting it to its neighbor with elastic garters

Metacarpophalangeal joints—Although less common than sprains of the interphalangeal joints, sprains of the metacarpophalangeal joints may follow hyperextension or twisting injuries or may result from the fingers being widely spread, as when they are caught in the spokes of a steering

wheel of a four-wheel-drive truck. Whenever the metacarpals or phalanges adjacent to these joints are fractured the joints are also probably sprained

The joint capsule and possibly the collateral ligament or the extensor tendon aponeurosis may be injured If the latter is torn on one side, the extensor tendon will subluxate between the metacarpal heads when the finger is flexed, giving rise to a snapping sensation Chip fractures of the margins of the adjacent articulating surfaces occur The signs are pain, limitation of motion and swelling around the joint X-rays rule out bone injury

In milder cases splinting in a slightly flexed position, as outlined for interphalangeal joint injuries, is appreciated by the patient and shortens convalescence In the more severe injuries in which the extensor aponeurosis is torn, an operative procedure may be necessary to correct the snapping tendon

Unstable sprain fractures—Whenever a large piece of bone is displaced with enough joint surface to make the joint unstable, surgical reduction and fixation is indicated

COMPOUND INJURIES OF THE SMALL JOINTS

A laceration of the radial side of the index finger which severs the collateral ligaments and lays open one of the interphalangeal joints is common If these injuries are clean, they will heal without disability All that is necessary is to tack the collateral ligament together, using a withdrawable figure-of-eight wire suture, close the skin and splint the finger until healing has taken place A description of the more extensive joint injuries is found in Chapter 3

CHAPTER TWELVE

Infections

ALTHOUGH INFECTIONS of the hand are not as common as they formerly were and the danger of rapid spread has been lessened by antibiotic and chemotherapy, the principles of treatment laid down by Kanavel based on the anatomy of the extremity are still applicable Infecting organisms are frequently extremely virulent, and the infectious material spreads through fascial and synovial spaces, causing necrosis of tendons, adhesions and fibrosis Any hand which has been damaged by infection is crippled just as it would be if injured by a crushing blow, and months of rehabilitation may be required Thus, the keynote of success in managing hand infections is prevention Injuries, if properly cared for, should heal without infection

Classification—It is customary to classify hand infections into three groups The first comprises localizing pyogenic infections, sometimes called minor infections, which include carbuncle, felon, web-space infection, subepithelial abscess, paronychia and infections in minor wounds The second group includes infections which spread by fascial spaces, the tendon sheaths or lymphatic channels Group 2 infections, sometimes called major infections, are often difficult to diagnose although each presents a definite clinical entity just as appendicitis or any other surgical disease does Pyogenic infections may also involve the bones and joints, either primarily or, more often, secondary to the soft tissue infection In the third group, most surgical textbooks include the more chronic nonpyogenic infections which involve the hand, such as tuberculosis, the granulomatous lesions, sporotrichosis, blastomycosis and syphilitic conditions

GENERAL PRINCIPLES OF MANAGEMENT —Diagnosis is based on anatomic knowledge The signs and symptoms depend on the tissue spaces involved and if these are understood the spread of infection can be anticipated One must particularly differentiate localizing from spreading infections since the treatment for each is quite different. One must be able to open the proper spaces Timing in instituting drainage is important, because in some cases delay results in destruction of tissue with subsequent fibrosis and permanent disability (Fig 159).

New antibiotic and chemotherapeutic agents are constantly being produced It is assumed that any practicing surgeon will keep abreast of these developments and use whatever drug is best suited to the individual infec-

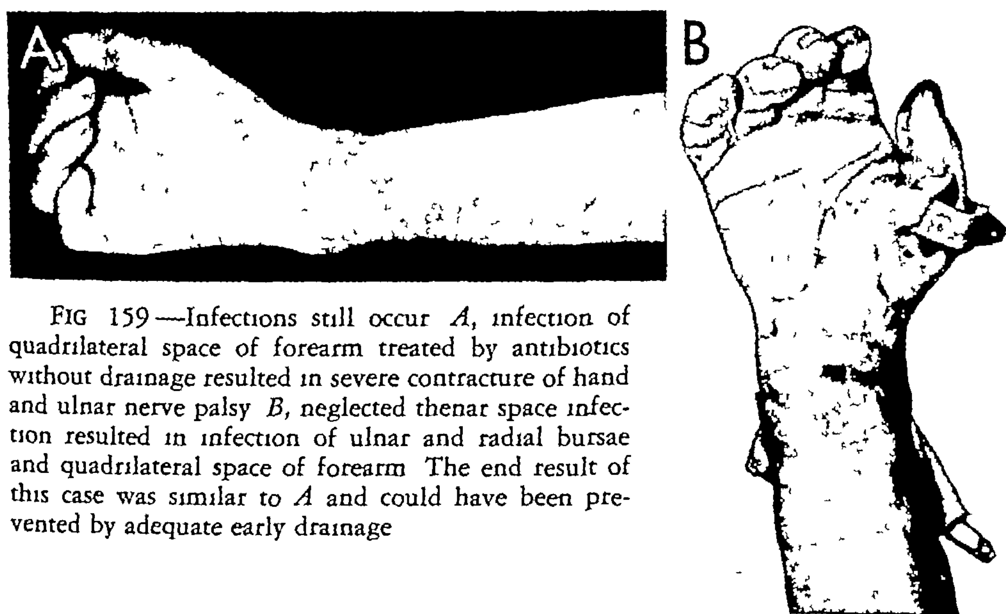


FIG 159 —Infections still occur *A*, infection of quadrilateral space of forearm treated by antibiotics without drainage resulted in severe contracture of hand and ulnar nerve palsy *B*, neglected thenar space infection resulted in infection of ulnar and radial bursae and quadrilateral space of forearm The end result of this case was similar to *A* and could have been prevented by adequate early drainage

tion A smear and culture should be made to identify the infecting organisms and, when possible, laboratory studies should be undertaken to determine what antibiotic the infecting organism is sensitive to In some minor hand infections treatment may be carried out with the patient ambulatory, but in all major infections hospitalization and suitable surgery are required

It is now common knowledge that antibiotics can mask surgical infections and cause delay in diagnosis and ultimately, perhaps, do more harm than good On more than one occasion, I have been consulted by patients with the typical clinical result of a severe hand infection (Fig 159), who had been treated by antibiotics without incision and drainage In these patients the apparent mild course resulting from the use of

antibiotics had lulled the treating physician into a false sense of security Often the diagnosis remained in doubt The oft repeated warning applies here as elsewhere—*Antibiotics do not take the place of surgery*

Surgical technic—General anesthesia is usually necessary The use of local anesthesia or ethyl chloride is mentioned only to be condemned, since spread of infection or gangrene of the skin often results The usual skin preparation and a bloodless field are just as important as in other hand operations Adequate assistance to retract the wound edges makes proper dissection possible The incision should provide adequate drainage and should be made either along the creases in the skin or along lines which will not interfere with function by contraction Incisions which cross important tactile areas or flexion creases or which allow tendons to herniate out of the wound are to be avoided Division of important nerves or blood vessels and unnecessary opening of spaces which are not involved should also be avoided

Drainage material—With a properly made incision, little drainage material is needed Whatever is used should be soft and should be removed within a day or two In general, all that is needed is to keep the wound edges apart for 24–48 hours with petrolatum gauze or with thin, soft, rubber-sheeting drains Even though all good surgical texts have for the past 25 years condemned through-and-through drains, patients are still seen in whom the flexor tendons in the fingers have been destroyed or osteomyelitis has been produced by such drainage

Postoperative care—The hand should be splinted in the position of function, moist dressings applied and the extremity kept elevated The hand automatically assumes the position of function if the wrist is dorsiflexed, the fingers allowed to assume a natural flexed position and the thumb brought around into opposition The infected hand should never be splinted with the fingers straight and the thumb alongside the palm Elevation of the hand on pillows or an armboard promotes venous return and decreases swelling

The operated area must not become contaminated by careless instrumentation or cross-infection Cleanliness is important, the removal of debris, crusts and soiled dressings helps to promote healing Constant supervision by the surgeon is necessary to keep the hand properly dressed and in the right position The patient should be encouraged to move the uninvolved parts as this will hasten recovery The injured part needs rest until drainage ceases and healing begins Then the maximal amount of motion possible without interfering with healing should be obtained For restoration of function, physical therapy may be necessary, but it is more

important to instruct the patient on proper motion beginning immediately after operation Movement of the fingers and thumb should be encouraged when the dressings are changed. Later on the patient uses hot soaks and wrings out cloths in hot water.

MINOR INFECTIONS

PARONYCHIA

A paronychia is an infection of the soft tissues adjacent to the sides and base of the nail. It begins superficial or deep to the nail or in the soft tissues just away from the edge of the nail and soon extends beneath the nail and along its edge and base, crossing from one side to the other In

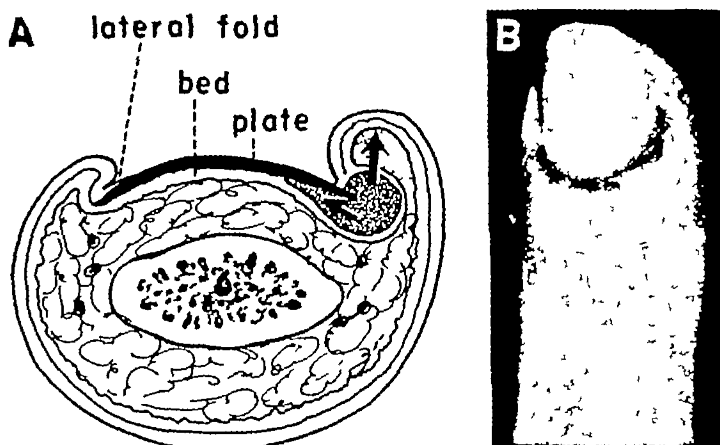


FIG 160—*A*, cross-section of finger showing development of paronychia *B*, typical case.

its final stage, a sac of pus forms which lifts the proximal half of the nail, eventually rupturing through the line between the skin and nail on the side (Fig 160)

These infections may follow a manicure, a hangnail or a puncture wound in the skin fold alongside the nail The symptoms are generally not severe There is some soreness of the tissues around the nail together with a little dull pain under the nail At times a complicating lymphangitis may cause pain to radiate up the arm, and red streaks and an axillary adenitis appear Later there may be persistent drainage if the dead portion of the nail is not removed, since it will act as a foreign body. Finally, there may be a small resistant granuloma in the sulcus where the nail was removed

TREATMENT—In the earliest stage when only a little redness is pres-

ent in the soft tissues along the nail, it may be possible to abort the process by giving the patient antibiotics and using moist packs with rest and elevation of the part However, most of these infections are due to a staphylococcus or streptococcus or a combination of these organisms, and the tendency is to early pus formation Sometimes a tiny abscess is detected in the fold alongside the nail, if this is drained before the infection extends beneath the nail, the disease may be arrested before the root of the nail becomes detached.

As soon as the process extends beneath the nail, drainage should be established by removing a portion of the nail The presence of pus here may be difficult to detect early, but usually there is a little tenderness along the edge of the nail It is better to make a small window here, even if no pus is present, than to allow extension of infection with separation

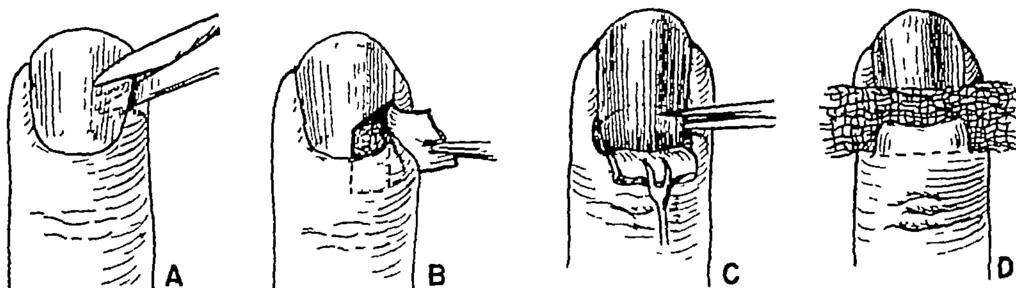


FIG 161 —Treatment of paronychia. *A* and *B*, in early infection, corner of nail is removed Wet packs are used and antibiotics given *C* and *D*, in severe cases, nail fold is turned back, entire base of nail removed and petrolatum gauze strip inserted

of the entire root of the nail. Local anesthesia cannot be used, but the window can be made using a block anesthesia at the base of the finger (Fig 9), although even this is dangerous in these cases and should be avoided if possible (Fig 11) When the patient is co-operative and phlegmatic, no anesthesia is necessary once the nail has separated. The tip of a sharp-pointed scissors is slipped beneath the nail along the side near the base As the tip of the scissors slides under the nail ⅛–¼ in , a drop of pus escapes This portion of the nail is cut through, lifted up with a pair of forceps and the scissor cut extended down under the fold so this part of the root can be removed (Fig 161, *A* and *B*) Early in the disease this will provide adequate drainage if moist packs are used and antibiotic therapy given

Such treatment may be carried out as an office procedure Daily visits are necessary at first, the nail fold being lifted up by a blunt probe to allow drainage to continue Antibiotics are given and moist packs kept

up two to three days If the infection has spread across the root of the nail, the entire root should be removed

In severe cases there is a loss of the covering epithelium over the matrix which ordinarily appears smooth and shiny An incision must then be made to allow the skin fold across the nail root to be lifted up (Fig 161, *C* and *D*) This procedure requires hospitalization and general anesthesia, it is much less used than it once was Julian Bruner of Iowa says that it is unnecessary, however, our British confreres continue to recommend it

To raise the fold, an incision is made extending proximally from each end of the lunula as far as the root of the nail extends The nail root is removed, and the fold is kept from becoming readherent by inserting a petrolatum gauze strip for 24–48 hours Only the nail root should be removed and only enough of it cut away so that the fold does not overlap it The rest of the nail is left in place and helps to protect the finger

Care should be taken to avoid injury to the matrix either at the time surgery is performed or during the later dressings If a granuloma forms, as sometimes happens in late, neglected cases, the same treatment is applicable These granulomas do not require cauterization or curettement, but adequate drainage should be provided and any foreign body removed The possibility of a carcinoma or a syphilitic process should be suspected if granulomas are not due to a paronychia

Subungual Abscess

Less common than paronychias, subungual abscesses are caused by foreign bodies or puncture wounds which enter under or perforate the tip of the nail They are usually most painful although very small. Tenderness directly over the abscess is present The treatment consists of removing a triangular piece of nail to unroof the abscess No special postoperative care is required beyond simple wet dressings for a day or so and protection of the area until the defect of the nail has a chance to grow out

Carbuncle

The second commonest minor infection of the hand is the carbuncle Carbuncles occur on the hair-bearing areas on the dorsum of the fingers, due to direct contamination from the nose, or are on the ulnar border of the hand from contact with infectious material such as may be found on a public writing desk If only one hair follicle is involved, there will be one little pustule which may evacuate itself spontaneously Usually, following trauma from self-treatment, redness, induration and swelling develop, but

there is little tendency to form an abscess even after four or five days In neglected cases the hand then becomes swollen and red streaks extend up the arm If moist packs are applied and further trauma prevented, pus will appear from several small openings Later the skin becomes necrotic, a larger opening develops and a greenish slough is extruded, leaving a granulation-lined cavity which heals rapidly

Prophylactic treatment is best, with no attempt made to squeeze pus or to open the infected area under local anesthesia Moist packs and elevation together with antibiotic therapy will cure most of these infections When the infection appears to be spreading despite conservative measures, the area may be opened by a crucial incision (Fig 162). This is

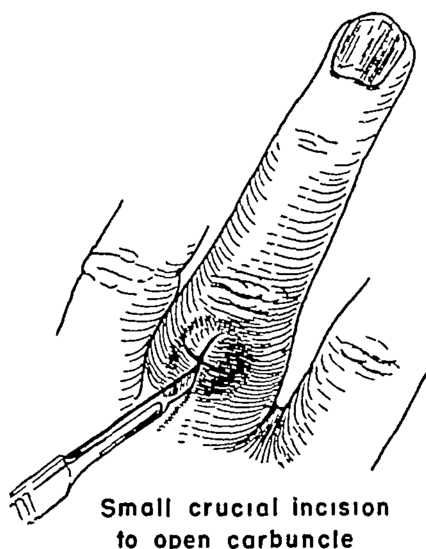


FIG 162—Incision for carbuncle (rarely necessary)

rarely necessary Excision of the carbuncle is definitely contraindicated Usually all that is needed is to wait until the slough has developed and to remove this by nicking the necrotic skin over it After the slough has separated, the wound should be kept clean and healing will occur rapidly

FELON

A felon is a localized infection in the anterior closed space of the pad of the distal segment of the finger Infections of the proximal and middle segments which are similar to felons in their etiology and symptoms are discussed under subcutaneous abscesses

The distal finger pad is anatomically a *closed space,* bounded superficially by the skin and deeply by the phalanx. Proximally it is closed off

by the attachment of the skin to the tendon sheath at the distal flexion crease The skin is bound to the periosteum by numerous perpendicular bands of connective tissue, between which are columns of fat containing sweat glands, blood vessels and nerves The arteries here supply both the diaphysis of the bone and the soft tissue

Most felons are due to known puncture wounds from contaminated needles, slivers, etc A few are apparently hematogenic in origin and sometimes a felon may occur in an infected hematoma following a contusion Within the closed space, compression of the nerves and blood vessels takes place as the tissues expand The symptoms progress rapidly. Since the blood supply of the diaphysis lies within the closed space, this part of the bone may become necrotic if compression is not relieved *

At the onset, the throbbing pain of a felon is characteristic, it keeps the patient awake at night The finger tip becomes tense, red and swollen Later, in neglected cases, there is spontaneous rupture to the outside The tip is then boggy with necrotic matter and will show one or more discharging sinuses By this time the pain and throbbing have subsided Leukocytosis and fever are proportional to the severity of the process In doubtful cases an elevated leukocyte count may be an indication for surgery X-rays of the infected finger will show no bone changes in early cases and will also rule out an unsuspected fracture which at times gives rise to symptoms simulating those of a felon

TREATMENT —In a few cases, when treatment is started early enough, the administration of antibiotics with rest, elevation and use of hot packs may cause the process to subside Antibiotic therapy will reduce the duration of morbidity but will not prevent suppuration or in most cases take the place of drainage A properly made incision will do much to relieve pain and hasten recovery and will cause much less eventual disability than spontaneous rupture The incision can be made under digital block or general anesthesia but should never be made by injecting local anesthesia along the site of the incision or by using ethyl chloride locally

There are two well recognized types of incisions, the fishmouth and the hockey-stick (Fig 163) The fishmouth incision is made straight across the end of the finger from side to side, cutting as close to the nail and phalanx as possible and going back far enough to relieve the tension on the perpendicular bands but avoiding the tendon sheath and joint If the incision is made close to the phalanx, the digital nerves are avoided The principal objection to the fishmouth incision is that, on healing, it

* Recent reports have raised some question as to whether this explanation of the pathogenesis of felon is correct.

often leaves a retracted sulcus in the finger tip. This sulcus can later be revised surgically Julian Bruner never uses the fishmouth

The hockey-stick or L-shaped incision is made along one side of the finger through the anterior quadrant, extending across the midline in depth but not across the finger tip This incision is more apt to interfere with the nerve supply and must be made even more carefully than the fishmouth to avoid cutting into the tendon sheath It does not produce a sulcus at the finger tip but is more apt to result in a painful scar A through-and-through incision of the distal finger pad is not recommended It does not provide adequate drainage and the skin distal to the incision frequently sloughs, resulting in a fishmouth scar without the benefits of the incision

If either of the recommended incisions is made early enough and proper postoperative care instituted, most of the inflammatory reaction will sub-

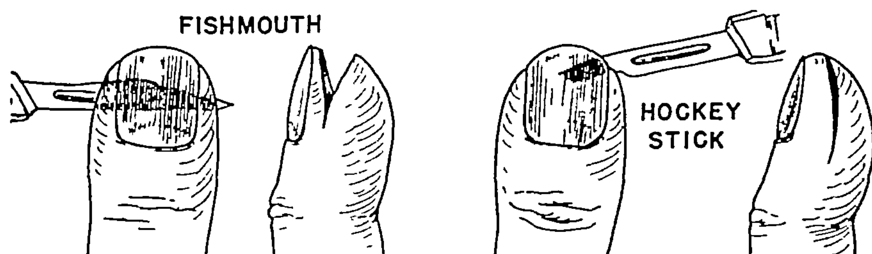


FIG 163 —Fishmouth and hockey-stick incisions for felon.

side in 24–48 hours Packs and drainage are then discontinued and the wound allowed to close

When the felon is seen only after draining sinuses are present or there is extensive necrosis inside the pulp, the treatment varies somewhat In these cases it is sometimes possible to establish adequate drainage by enlarging the already present draining sinus The classic incision is often necessary, but more necrosis may follow. Persistent drainage indicates the presence of necrotic material or at times a sequestrum of the phalanx In no instance should anything be removed except for bits of bone which are already separated and soft tissue which separates spontaneously. Although the x-ray will show extensive demineralization of the bone, which may be improperly interpreted as an osteomyelitis (Fig 164), no bone should be curetted or otherwise removed surgically Prolonged use of dressings is necessary

In children the diaphysis sometimes may be sequestrated and later will regenerate The principle in treatment is adequate drainage of the soft parts with proper dressing of the wound

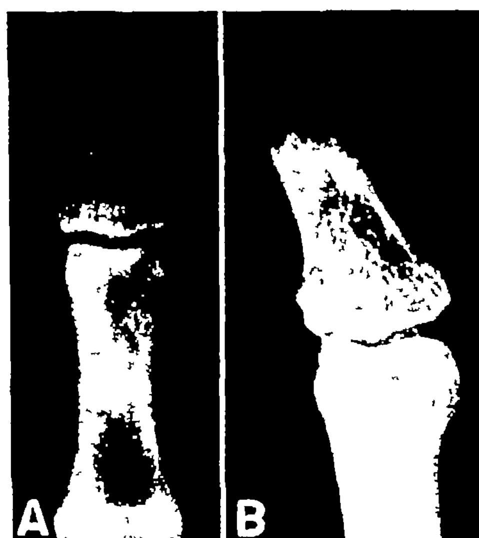


FIG 164—Felon in which portion of phalanx was sequestrated Note demineralized appearance early (*A*) and loss of tuft later (*B*)

One is cautioned not to consider every infection in the finger pad as a felon and to treat it as such Some puncture wounds in this region may result in a small, localized abscess which will not produce a felon Proper treatment in these cases is to open the abscess

SUBEPITHELIAL ABSCESS

A subepithelial abscess is one located between the epithelium and the deep layer of the skin These abscesses are common in the distal palm of workers where cracks occur around calluses and may also be found over the palmar skin of the digits from small puncture wounds or trauma. Subepithelial abscesses are of importance in that they frequently communicate with a subcutaneous abscess in the proximal segment of the finger or a web-space abscess in the distal palm In treating them, the surgeon should look for a tiny channel which connects the subepithelial abscess with the deeper tissues The epithelium over the abscess should be removed and a communicating passage sought When present, it should be explored and proper drainage for the deep subcutaneous abscess instituted

SUBCUTANEOUS AND WEB-SPACE ABSCESSES

Subcutaneous abscesses found in the front of the hand are of two types: those in the middle segment of the finger which may simulate a felon of

often leaves a retracted sulcus in the finger tip This sulcus can later be revised surgically Julian Bruner never uses the fishmouth

The hockey-stick or L-shaped incision is made along one side of the finger through the anterior quadrant, extending across the midline in depth but not across the finger tip This incision is more apt to interfere with the nerve supply and must be made even more carefully than the fishmouth to avoid cutting into the tendon sheath It does not produce a sulcus at the finger tip but is more apt to result in a painful scar A through-and-through incision of the distal finger pad is not recommended It does not provide adequate drainage and the skin distal to the incision frequently sloughs, resulting in a fishmouth scar without the benefits of the incision

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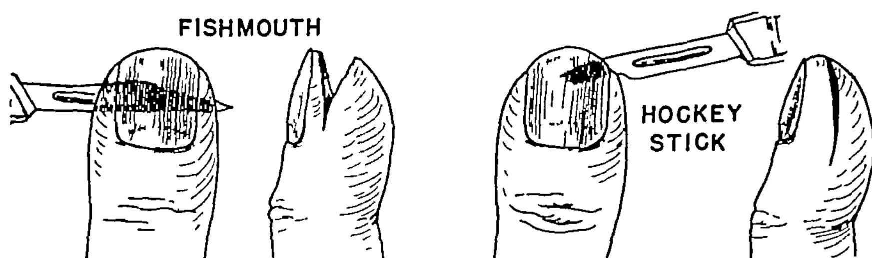


FIG 163 —Fishmouth and hockey-stick incisions for felon

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When the felon is seen only after draining sinuses are present or there is extensive necrosis inside the pulp, the treatment varies somewhat. In these cases it is sometimes possible to establish adequate drainage by enlarging the already present draining sinus The classic incision is often necessary, but more necrosis may follow Persistent drainage indicates the presence of necrotic material or at times a sequestrum of the phalanx. In no instance should anything be removed except for bits of bone which are already separated and soft tissue which separates spontaneously Although the x-ray will show extensive demineralization of the bone, which may be improperly interpreted as an osteomyelitis (Fig 164), no bone should be curetted or otherwise removed surgically Prolonged use of dressings is necessary

In children the diaphysis sometimes may be sequestrated and later will regenerate The principle in treatment is adequate drainage of the soft parts with proper dressing of the wound

fection If the proper midlateral incision is made before the sheath is invaded, the sheath will not be swollen or involved and need not be opened.

In the proximal segment of the finger the subcutaneous space is not closed Pus formed here spreads rapidly into the space beneath the skin of the distal palm and across the superficial transverse metacarpal ligament into the space between the fingers in the web dorsally Likewise, an abscess arising in the distal palm ruptures through the thinned-out layer of palmar fascia and spreads to the web behind, and laterally along the sides of the finger and into the subcutaneous tissues of the proximal segment This is the frog felon or web-space infection In either web-space or proximal segment finger abscesses, after an incubation period of several days, swelling starts in the distal palm or adjacent finger and in about 24 hours extends to fill the entire space. The fingers are spread, and the proximal segment of the finger and distal palm are tender to pressure The constitutional reaction is moderately severe, with fever and leukocytosis Owing to the swelling, there may be partial inability to flex the finger, particularly at the proximal joint, though the distal joint still moves painlessly unless the tendon sheath is involved Spread into one of the palmar spaces or into a tendon sheath may take place either by direct extension or by following the lumbrical canal

TREATMENT —These patients require hospitalization and close observation As with a felon, an early incision in doubtful cases is much less disabling than an incision made after the process has extended beyond the space A midlateral incision in the finger, placed dorsal to the proper digital artery and nerve and volar to the tendon sheath, permits the finger to be explored without harm Even if no frank pus is encountered, there is frequently edema of the tissues with escape of dirty fluid The portion of the distal palm which communicates with this space should also be explored if it shows signs of inflammation This is done through an incision which parallels the distal transverse palmar crease, avoiding nerves and vessels in this region (Fig 165) These incisions require a bloodless field, and general anesthesia should be used

Postoperative care as described for infections in general must be instituted

INFECTIONS SPREADING BY TENDON SHEATHS AND FASCIAL SPACES

ANATOMIC RELATIONS —Tendon sheaths and fascial spaces are closely related anatomically although the treatment of infections involving them differs

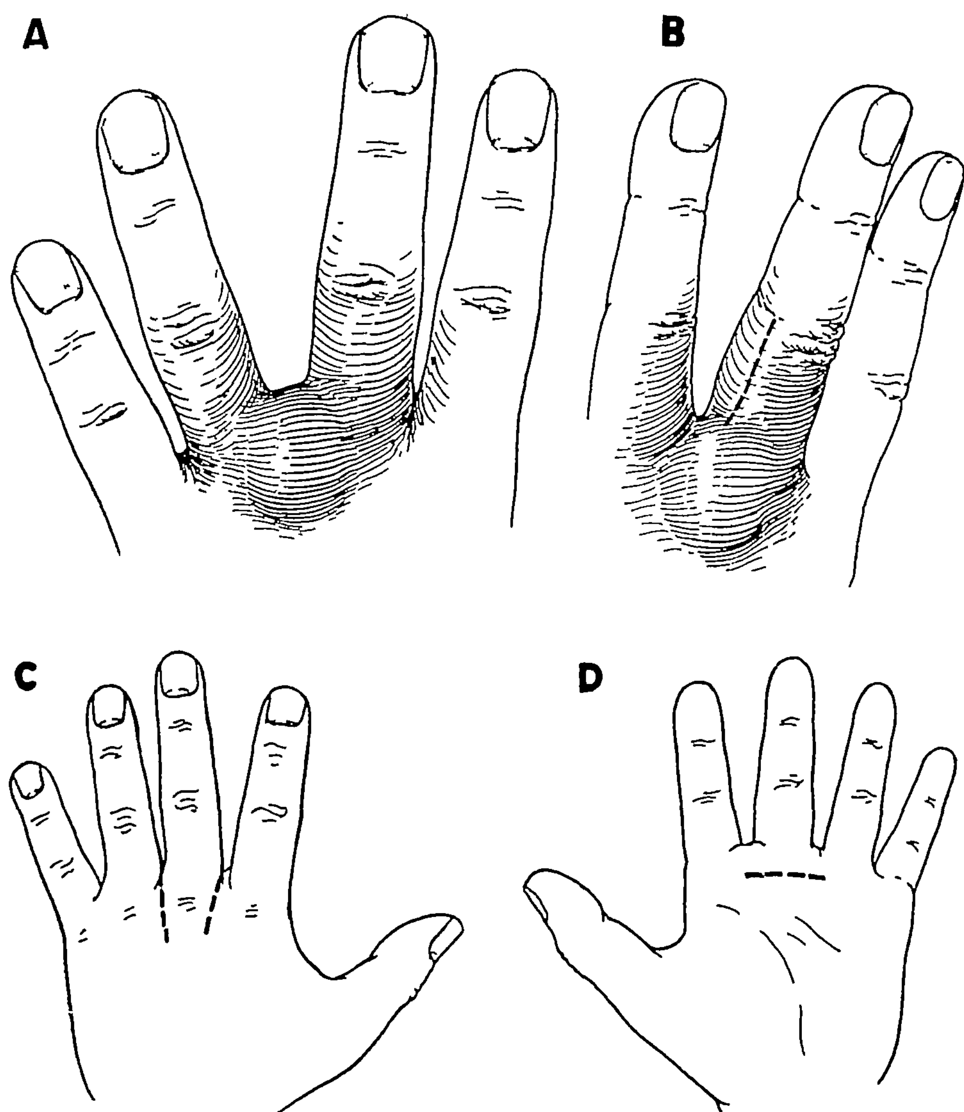


FIG 165 —*A*, subcutaneous infection of proximal segment of finger with spread into web Note how fingers are held spread apart, palmar swelling is not prominent. *B*, incision used to open finger; alternative incisions in *C* are rarely necessary *D*, incision for exploration in palm follows distal flexion crease

the distal phalanx, and those which involve the distal palm or proximal segment of the finger and produce web-space infection or frog felon

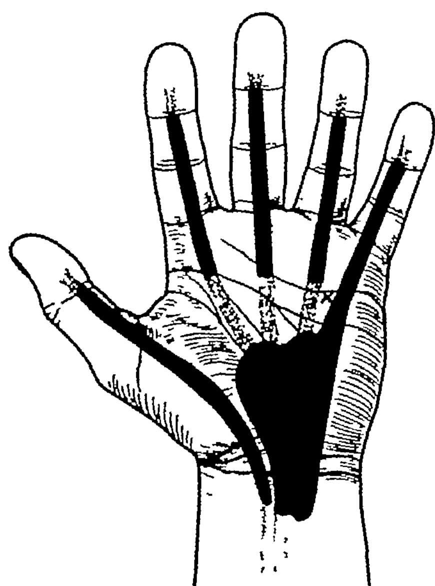
The front of the middle segment of the finger is anatomically a closed space An infection in the middle segment gives rise to symptoms of throbbing and localized pain and tenderness which are similar to those of a felon in the distal phalanx but are usually less severe Treatment principles are also about the same This infection may readily invade the tendon sheath and is often misdiagnosed as a flexor tendon sheath in-

radial side it is bounded by the juncture of the palmar fascia with the adductor pollicis fascia

The tendon sheaths of the index, long and ring fingers in the palm adjacent to the palmar spaces are separated from them by a thin layer of fascia. The ulnar bursa also lies under the base of the middle palmar space

Of relatively minor importance is the hypothenar space which is actually a muscular compartment well separated from the rest of the spaces in the hand by the palmar fascia

There are two spaces on the back of the hand One, called the dorsal subcutaneous space, lies between the subcutaneous fascia and the extensor



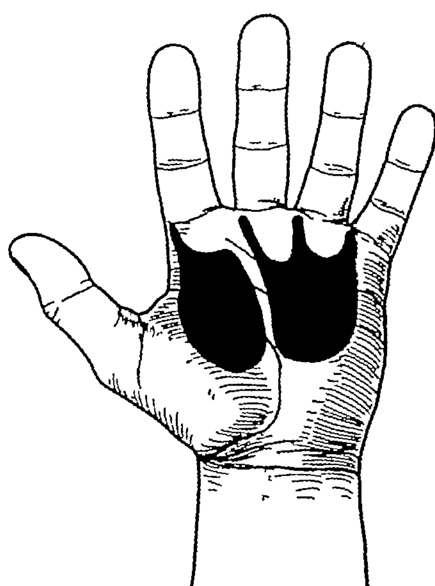


FIG 166 *(left)* —Usual anatomic relationship of tendon sheaths and radial and ulnar bursae X, Kanavel's point.

FIG 167 *(right)* —Approximate locations of thenar and middle palmar spaces and lumbrical canals

tendons The second lies between the aponeurosis of the extensor tendons and the fascia overlying the metacarpals and interosseous muscles. This is called the subaponeurotic space. The only communication between this space and the palm is by way of the webs of the fingers. There are short tendon sheaths on the dorsum of the hand underneath the dorsal carpal ligament They are rarely involved in a suppurative process.

TENOSYNOVITIS

Acute, suppurative tenosynovitis is a rapidly spreading infection of the flexor tendon sheaths of the hand This is the one infection of the hand

The flexor tendons of the digits and thumb are encased in closed synovial sacs which normally contain a small amount of colorless fluid In the index, middle and ring fingers these closed sacs usually extend from the base of the distal phalanges to the metacarpophalangeal joints or approximately the level of the main transverse palmar crease The sheath of the little finger is pinched off proximally at about this same level but communicates with the *ulnar bursa* which extends under the transverse carpal ligament and up into the forearm for about 1 in beyond the wrist This bursa in the wrist region encloses all the flexor tendons of the fingers The tendons of the index, long and ring fingers are invaginated into the bursa in such a way that three pouches are formed, one lying above the tendons, one between the superficial and deep tendons and one beneath the tendons over the interosseous membrane and the pronator quadratus muscle This last pouch is the one which communicates with the flexor sheath of the little finger The sheath covering the long flexor of the thumb is likewise constricted at the metacarpophalangeal joint but joins directly with the *radial bursa* which extends into the wrist alongside the ulnar bursa and communicates with it under the transverse carpal ligament (Fig 166)

The *fascial spaces* of the hand which are of special surgical importance are the middle palmar space and the thenar space Both lie deep to the flexor tendons in the palm, their posterior wall being formed by the fascia overlying the deep intrinsic muscles They are separated from each other by a septum along the middle metacarpal

The *middle palmar space* lies in the ulnar half of the hand between the fascia overlying the interosseous muscles and the fascia on which the flexor tendons of the long, ring and little fingers rest Proximally, the space ends at about the level of the transverse carpal ligament and distally it continues out along the fingers by way of the lumbrical canals of the long, ring and little fingers It is bounded on the radial side by a layer of fascia which is attached to the middle metacarpal bone and on the ulnar side by fascia which is attached to the fifth metacarpal bone (Fig 167).

The *thenar space* lies between the fascia overlying the adductor muscles and the fascia which is deep to the flexor tendon of the index finger and the adjacent nerves and vessels Proximally it extends as far as the distal edge of the transverse carpal ligament and distally it is continuous with the lumbrical canal of the index finger and occasionally with that of the middle finger On the ulnar side the septum along the middle metacarpal separates the thenar space from the middle palmar space. On the

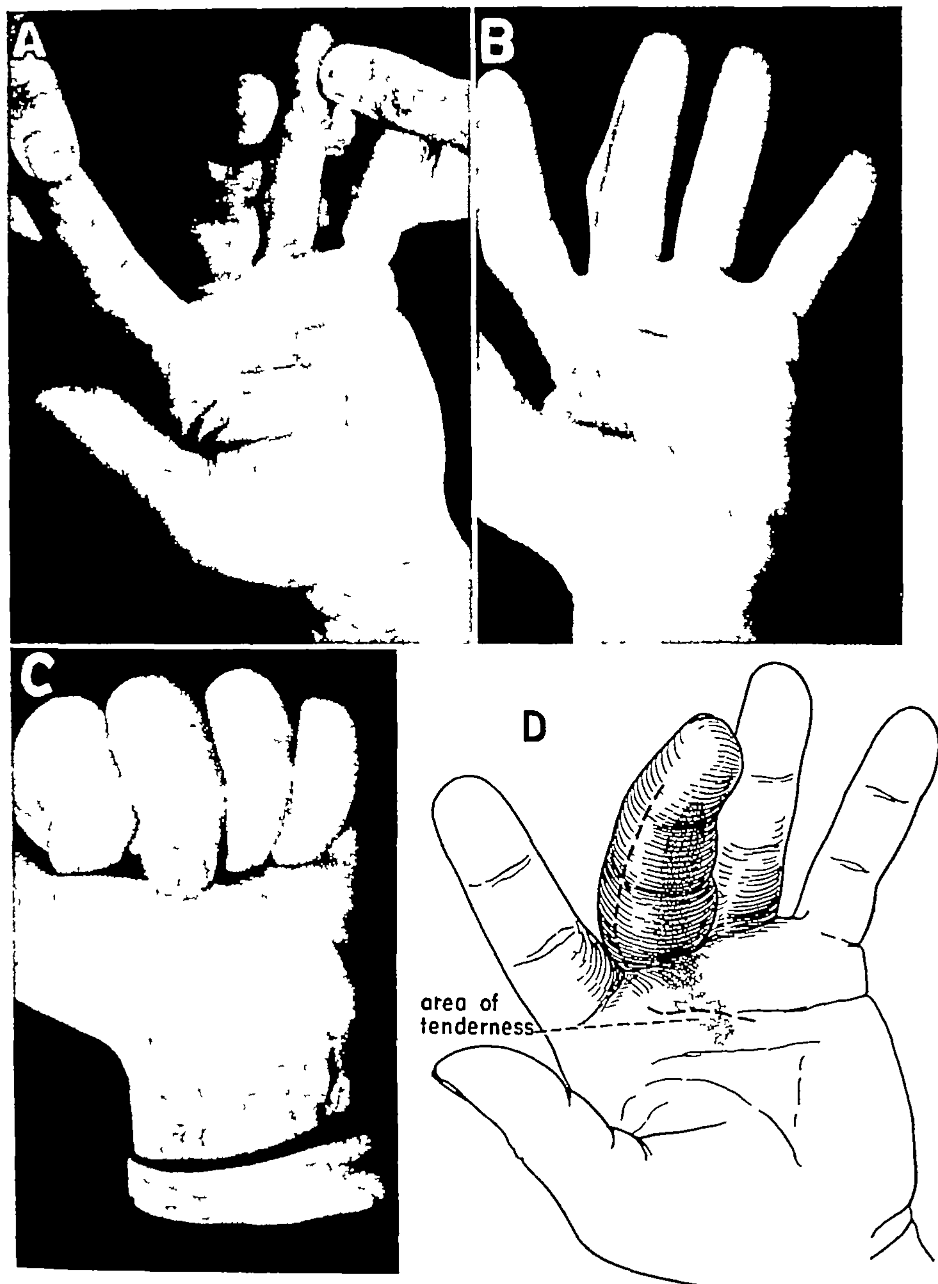


FIG 168 —*A*, suppurative tenosynovitis with characteristic swelling and fixed flexion of finger 48 hours after onset. *B* and *C*, two months after treatment (incisions marked with ink), *C* shows amount of flexion *D*, diagram of case, showing incisions used and area of tenderness

that requires immediate surgical intervention Most of these infections start from a puncture wound or laceration on the volar surface of the digit At the flexion creases there is no subcutaneous padding and a slight wound easily penetrates the underlying sheath. The tendon sheaths may also be accidentally infected surgically when a felon or a subcutaneous abscess of either proximal finger segment is opened Extension from a subcutaneous or palmar infection or extension of an infected joint into the sheath may cause tenosynovitis A few cases are metastatic, usually gonorrheal Dorsal infections and paronychias usually are not responsible for tenosynovitis

The infectious process spreads rapidly throughout the sheath, aided in its early migration by the movements of the finger. Once the sheath is distended, there is swelling of the tendon with interference of its blood supply, resulting in necrosis This may take only a few hours In the index, long and ring fingers the process is usually arrested temporarily within the confines of the tendon sheath and a characteristic clinical condition is produced Infection starting in either the thumb or little finger spreads around the two large bursae, that is, from the thumb up the radial bursa into the wrist and down the ulnar bursa into the little finger or, if the little finger is involved, this process in reverse

DIAGNOSIS —The patient with a tendon sheath infection usually seeks medical care early. The four cardinal signs are symmetrical swelling of the whole finger, a fixed, slightly flexed position, pronounced pain on attempted extension either actively or passively, and marked tenderness throughout the region of the tendon sheath with maximal tenderness where the tendon sheath crosses the distal crease of the palm (Fig 168). Some swelling of the rest of the hand is present, with edema of the dorsum. There are fever and leukocytosis Although early cases show only swelling, as the condition progresses the involved finger becomes diffusely reddened

These symptoms may persist for several days in the *index, long or ring finger* before the abscess ruptures into one of the fascial spaces in the palm In the *thumb* or *little finger,* extension takes place by way of the bursae and later there is a spread into the space in the forearm between the superficial and deep flexor muscles The bursa above the wrist is then palpable and the transverse carpal ligament can be seen as an hourglass constriction across the volar surface of the wrist. In most cases the radial bursa communicates with the ulnar bursa in the wrist and both the thumb and little finger will soon assume the characteristic picture of tenosynovitis. That is, the finger or thumb is held rigidly in slight flexion and any

When a tendon sheath infection occurs in an open wound with a severed tendon, some of the signs are lacking, especially the pain produced by attempted extension of the finger Other signs will be present but to a lesser degree

TREATMENT—An infected tendon sheath should be opened as soon as possible after diagnosis is made (Fig 168, *D*) This procedure is properly carried out in a bloodless field and with the patient under general anesthesia. The skin of the hand should be carefully prepared as in any elective hand operation

The incision to open the sheath should lie along the side of the finger and not in front or anterolaterally It is customary to make the incision on the radial side of the index finger and on the ulnar side of the other fingers The dorsal tip of the flexion creases on the side of the finger is the correct level for a proper midlateral incision This incision lies dorsal to the proper volar digital artery and nerve and not volar as was suggested by Kanavel After the skin is incised along the midlateral line, the soft tissues are retracted volarward, exposing the tendon sheath which can then be easily inspected When the sheath is not involved, the tendon can be seen through the sheath opposite the joints, still white and shiny and moving freely when the finger is flexed and extended When the sheath is infected, it is tense and opaque and as soon as it is opened turbid fluid or frank pus, under pressure, escapes The infected sheath should be opened from the distal flexion crease of the finger as far proximally as the web of the finger will permit A second incision along the distal palmar crease should then be made and the culdesac of the tendon in the palm opened (Figs 168, *D*, and 169, *a-1*)

After the incisions are made, the wounds are held apart by strips of rubber or petrolatum gauze which extend down but do not enter the tendon sheath Through-and-through drainage, hard rubber drainage or rubber tubing should not be used

In the thumb, incision is usually made along the ulnar border and continued into the palm (Fig 169, *c*), paralleling the line of the thenar crease This incision avoids injury to the branches of the median nerves, especially the motor branch, and opens the radial bursa distally

Either the radial or ulnar bursa is usually opened in the forearm by an incision made on the ulnar side of the wrist between the flexor tendons and the ulna (Fig 169, *e*) The dorsal branch of the ulnar nerve and the flexor ulnaris are retracted volarward The distended bursa can be seen between the flexor tendons and the pronator quadratus If the infection is severe, through-and-through drainage may be established in this region

attempt to extend it will cause severe pain When in doubt as to whether the infection has spread from one bursa to another, the presence or absence of this sign may be an important factor in deciding whether or not to open the associated sheath

Certain of the complications of tendon sheath infections will be discussed under infections of the fascial spaces. Neglected tendon sheath infections spread into the fascial spaces. When the tendon sheath ruptures there is amelioration of the pain, rigidity and tenderness in the fingers but the systemic reaction increases The index and occasionally the long finger sheath may rupture into the thenar space This produces swelling of the space accompanied by abduction of the thumb, resulting in a tender golfball-like mass in the web between the thumb and index finger From rupture of the tendon sheaths of the ring or middle fingers, the middle palmar space is usually invaded The result is a loss of palmar concavity with a grayish avascular swelling of the distal transverse palmar crease In either palmar space infection, as the swelling continues the lumbrical canals are invaded, with swelling of the web

In the unusual case in which the little finger sheath does not connect with the ulnar bursa, it ruptures into the middle palmar space Usually this sheath communicates with the ulnar bursa which, when involved, fills up in an hourglass fashion, extending above the wrist and within the palm with a constriction in the middle due to the transverse carpal ligament There is then localized tenderness over the point where the bursa lies closest to the surface at the juncture of the middle palmar crease and the hypothenar eminence (Kanavel's point) Involvement of the ulnar bursa also causes flexion of the index, middle and ring fingers with some pain on extending them Signs of tenosynovitis of the thumb soon follow as the radial bursa fills and infection extends distally When infection ruptures into the forearm, it first lies beneath the flexor tendons in the space between them and the pronator quadratus, then spreads upward between the superficial and deep flexor muscles and points on the ulnar side in the upper third of the arm The entire hand or forearm is red, swollen, tender and edematous Toxicity is pronounced, with a high temperature, rapid pulse, etc.

Differential diagnosis of a tenosynovitis of a finger and an infection of one of the subcutaneous spaces is occasionally difficult With infection of the subcutaneous space there may be considerable pain, tenderness and swelling of the finger and a certain degree of fixation in flexion, but the patient is able to flex the terminal joint voluntarily and the outline of tenderness does not follow the anatomic extent of the tendon sheath

are incised, and the distended bursa will not be clear or transparent as is a normal bursa

AFTER-CARE —Postoperative care is just as important as a correct incision Continuous hot, moist dressings are applied to the extremity and antibiotic substances given in therapeutic doses The hand meanwhile is kept elevated and in the position of function As soon as drainage ceases, usually at the end of 48 hours, all drains should be removed and the patient encouraged to start moving the finger. The packs should be kept on for another few days, stopping if skin maceration occurs Hot soaks for an hour three times a day with grease gauze dressings between soaks are used during convalescence Physical therapy in these cases is only an adjunct, it cannot restore a finger to usefulness after the tendon has become adherent due to late or inadequate drainage or to failure to start exercises early Since the advent of antibiotics a good percentage of patients obtain complete restoration of function.

In more complicated cases with persistent drainage, further treatment is required If the tendon becomes necrotic, it must be removed Occasionally there is osteomyelitis or arthritis of one of the interphalangeal joints However, the x-ray appearance of bones in these cases is misleading, and any attempt to curet or chisel away supposedly involved areas based on the x-ray findings will lead to further damage and spread of the infection Drainage of the soft parts is important and only such bone or joint material as is actually sequestrated should be removed. The finger which has been ravaged by complicated infection of this type will inevitably become stiff and may require amputation later. Amputation should not be done as long as any acute infection is present When a sheath and joint are both infected, amputation is carried out through the involved joint except in the case of the thumb

TENOSYNOVITIS OF DORSAL TENDON SHEATHS

Where the extensor tendons of the fingers and thumbs pass under the dorsal carpal ligament they are surrounded by tendon sheaths These sheaths extend from just proximal to the ligament to the bases of the metacarpals There are also sheaths for the extensors of the wrist and for the long abductor of the thumb which begin at about the same level and extend as far as the insertion of the tendons Infection of these sheaths is quite rare but may follow wounds in this region. Symptoms correspond in a general way to those of flexor tendon synovitis but are less severe, and passive flexion rather than extension of the finger causes pain

by passing a hemostat through the ulnar incision to the opposite side of the wrist and cutting down on the hemostat This is seldom necessary The ulnar bursa, however, must also be opened by an incision in the palm (Fig 169, *d*). This incision runs from the distal flexion crease of the palm to the transverse carpal ligament and parallels the base of the hy-

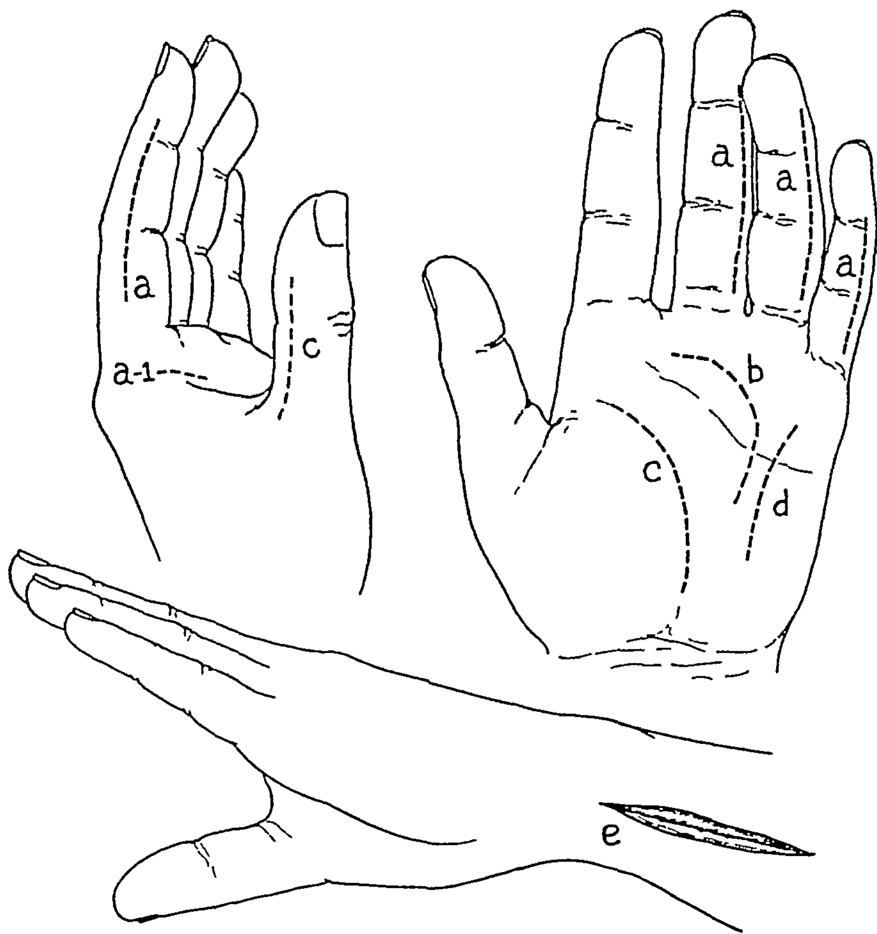


FIG 169—Incisions for opening hand infections *a*, digital sheaths, *a-1*, through distal palmar crease for proximal culdesac of tendon, *b*, middle palmar space, *c*, thumb flexor and radial bursa, *d*, ulnar bursa, *e*, ulnar bursa and subtendinous space above wrist.

pothenar eminence The sensory branches of the ulnar nerve in the palm which overlie the tendons must be avoided when this incision is made

In doubtful cases in which either the radial or ulnar bursa is involved but it is not apparent whether or not the opposite bursa is involved, it is better to make an incision through a sterile field and to inspect the suspected bursa than to leave an involved bursa undrained The tissues around an infected bursa usually present considerable edema when they

are incised, and the distended bursa will not be clear or transparent as is a normal bursa

AFTER-CARE —Postoperative care is just as important as a correct incision Continuous hot, moist dressings are applied to the extremity and antibiotic substances given in therapeutic doses The hand meanwhile is kept elevated and in the position of function As soon as drainage ceases, usually at the end of 48 hours, all drains should be removed and the patient encouraged to start moving the finger The packs should be kept on for another few days, stopping if skin maceration occurs Hot soaks for an hour three times a day with grease gauze dressings between soaks are used during convalescence Physical therapy in these cases is only an adjunct, it cannot restore a finger to usefulness after the tendon has become adherent due to late or inadequate drainage or to failure to start exercises early Since the advent of antibiotics a good percentage of patients obtain complete restoration of function

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TREATMENT—Incision over the involved area should be carried out as early as possible to avoid the possibility of extension into the carpal joints

PALMAR SPACE ABSCESSES

The thenar space and, less often, the middle palmar space may be infected directly by wounds of the palm of the hand They are also infected secondarily through rupture of a tenosynovitis or by extension of

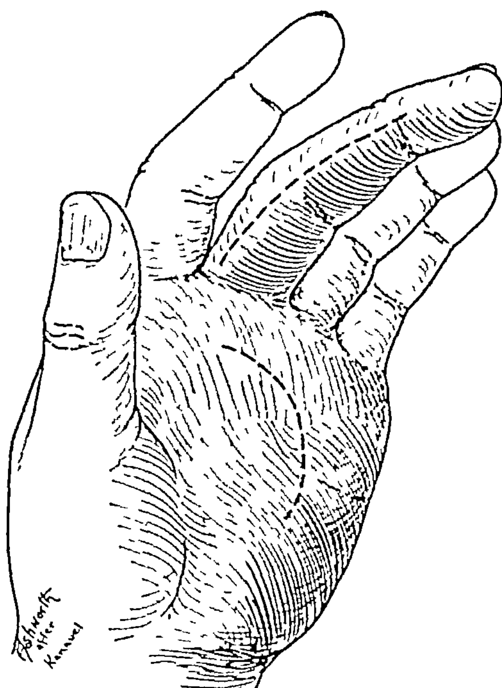


FIG 170—Diagram of palmar space infection following tenosynovitis of long finger Guide lines for incisions are shown

infection from the web spaces The ulnar bursa overlies the midpalmar space and infections of this bursa may involve this space The thenar space becomes infected from rupture of the radial bursa or from rupture of a tendon sheath infection of the thumb or index finger

MIDPALMAR SPACE—In infections of the middle palmar space the palm becomes indurated, with tenderness more or less outlined to the space and loss of concavity Characteristically the distal palmar crease becomes pale and indurated The dorsum of the hand is swollen and the lumbrical canals become tender and swollen as they are involved There is some pain on straightening the middle and ring fingers, and the lumbrical and interosseous muscles show some loss of function (Fig 170)

Treatment.—A palmar space infection, unlike a tenosynovitis, is not an acute emergency demanding immediate drainage The progress of symptoms and development of signs in these abscesses are also more gradual After the diagnosis is assured, the hand can be opened as an early elective procedure

The middle palmar space should be drained through an incision which parallels the distal palmar crease and turns down toward the heel of the palm along the line of the fourth metacarpal (Fig. 169, *b*). The flexor tendons, digital nerves and vessels of the middle and ring fingers are retracted and the fascial space beneath them exposed This space should be opened as widely as possible without severing any nerves or tendons Drainage should not be to the dorsum of the hand, since infection is al-

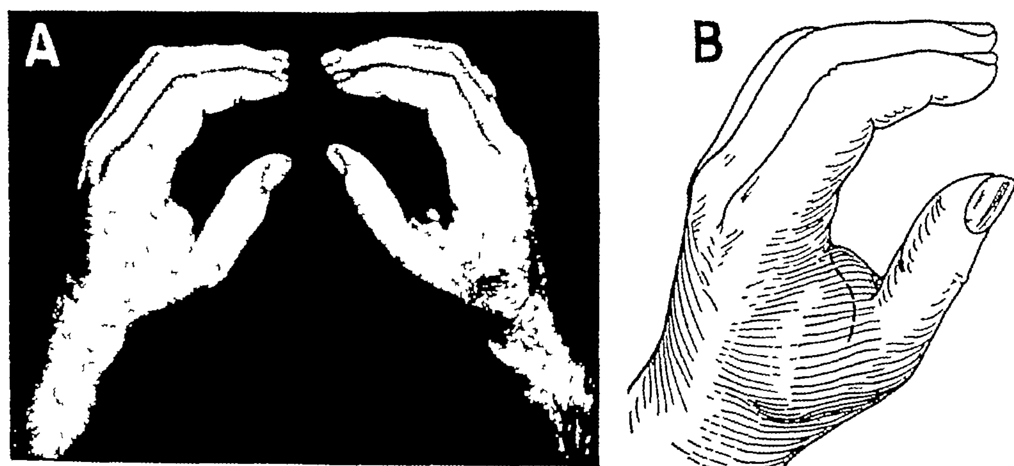


FIG 171—Early thenar space infection *A,* swelling in thumb web of left hand, *B,* diagram showing line of incision used

most sure to develop in the bones and give rise to persistent sinuses. The palmar skin is kept apart by petrolatum gauze, but no drainage material should lie against the tendons Drains are removed after about 48 hours and the usual hot, moist dressings kept up for another day or two, after which hot soaks and active exercises are instituted

THENAR SPACE—The characteristic symptoms of thenar space abscesses are pain, swelling and tenderness, with formation of a tender, golfball-like tumor deep in the web between the thumb and index finger (Fig 171) The thumb is forced away from the hand by this mass, and pronounced tenderness is present both dorsally and on the palm As extension occurs, the lumbrical canal and radial side of the index finger become involved There is also some pain on moving the thumb or index finger

Treatment—Infection of the thenar space, like infection of the midpalmar space, requires drainage, not as an immediate emergency but as soon as convenient after diagnosis Two types of incision have been devised to drain this space One parallels the edge of the web between the thumb and index finger, and the other splits the web but attempts to avoid injury to the first dorsal interosseous muscle (Fig 171). Either must be made long enough to give adequate drainage, and either is easily made since there are no important nerves, vessels or tendons in this region Dissection is then made between the first dorsal interosseous muscle and the muscle of the thenar eminence, and a hemostat is pushed into the abscess here An incision may also be made around the base of the thenar eminence on the palmar side of the hand, avoiding the motor branch of the median nerve, but this incision is rarely necessary. If the incision along the web is made, a soft rubber drain should be inserted and left in for 48 hours The usual postoperative care is carried out

Infections of Dorsal Subaponeurotic Space

This space lies beneath the tendons on the dorsum of the hand. It is the space between the tendons above and the metacarpals and interosseous muscles below. Rupture of a dorsal tendon sheath infection or a direct wound may lead to infection in this region Considerable swelling and tenderness and pain on movement of the fingers are the initial symptoms As the infection extends, pus points around the arch of the dorsum of the hand and in the webs between the fingers

Treatment—The incisions to open this space are made in the webs between the tendons and also along the ulnar border of the dorsum of the hand, avoiding the tendons and the dorsal branch of the ulnar nerve

Infections of Quadrilateral Space of Forearm

This space lies between the pronator quadratus muscle and the flexor tendons at the wrist, the interosseous membrane and the deep flexor tendons in the midforearm and the bellies of the profundus and sublimis muscles in the upper arm proximal to the origin of the profundus muscles It is quite large when distended by infection and, as it fills, the pus gradually rides forward over the profundus tendons and finally points between the flexor sublimis and flexor carpi ulnaris

The usual source of infection in this region is rupture of the radial or ulnar bursa at the wrist Symptoms include a brawny induration and

swelling on the front of the forearm, extending from the upper border of the transverse carpal ligament most of the way to the elbow, severe pain due to the inflammatory reaction around the median nerve, and paresthesia and numbness of the hand The wrist and digits are held flexed (see Fig 159)

TREATMENT—An incision is made on the ulnar border of the wrist, as for opening the ulnar bursa, and extended about 3 in proximal to the ulnar styloid (Fig 169, *e*) The dorsal branch of the ulnar nerve is displaced volarward and the tendons lifted from the pronator quadratus A similar incision is made on the radial side of the wrist, with care taken to avoid the sensory branch of the radial nerve and the tendons of the thumb Another incision is made in the upper forearm between the flexor digitorum sublimis and flexor carpi ulnaris muscles This incision anticipates the pointing of pus in this region

LYMPHANGITIS

Acute lymphangitis is a fulminating, spreading infection which follows the course of the lymphatics, moving up the arm to the axilla and at times passing under the clavicle into the subclavian nodes Most of these infections follow a trivial injury which becomes infected with a virulent strain of streptococcus or staphylococcus which has become human acclimatized The hand is richly supplied with lymphatic vessels which form a dense network of vessels over the palm and digits These in turn drain into one or more collecting trunks which run up the dorsum and volar surfaces of the arm Those from the ulnar side of the hand and forearm follow the basilic vein, and some of them enter the epitrochlear node but most continue to the axilla Those on the radial side of the forearm follow the cephalic vein, while a few from the middle fingers follow the course of the basilic vein

Most cases of lymphangitis can be definitely said to start from mistreatment of a minor infection or wound There may be an incubation period of a few days to a week and then, following some additional trauma or the injudicious use of local anesthesia, there is a sudden onset of chills, fever and pain, with red streaks radiating up the forearm The area around the original wound is red to a purplish red in color One or two red streaks on the forearm can be seen to lead to enlarged, tender nodes in the axilla Occasionally the infection passes directly into the chest and the axillary nodes are not swollen

There are three general classes of infection In one the symptoms are

comparatively mild and there is a long incubation period In some of these patients nothing more than suppuration of the axillary nodes is present by the time they reach the physician, the original infected site and subsequent lymphangitis having been unnoticed by the patient. More severe cases are those in which the infection subsides but is followed by suppuration in the hand In this type of case there may subsequently be a tendon sheath infection although the tendon sheath was not involved primarily. The sheath should not be opened until infection is definitely present. There may also be abscesses of the hand or forearm (Fig 172) The most severe cases are those which formerly terminated fatally. These were often seen in surgeons who cut themselves while doing tonsillec-

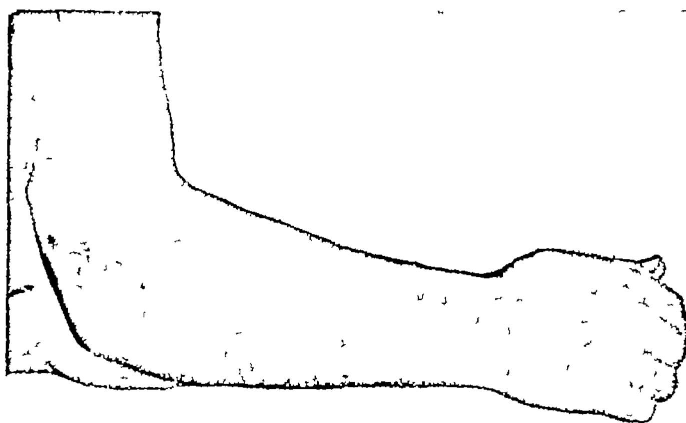


FIG 172 —Infections still occur diffuse cellulitis with multiple abscesses of upper extremity Patient was unconscious on hospitalization, improvement followed incision and drainage of abscesses and antibiotic therapy

tomies or in pathologists who pricked themselves while doing autopsies on unembalmed bodies The onset of the symptoms was rapid, the lesion was usually on the volar surface of the index or middle finger and all treatment was unavailing

TREATMENT —The advent of antibiotics has had the same effect on lymphangitis that it has had on pneumonia, except in penicillin-resistant and certain anaerobic infections In fairly large hospitals with outpatient departments in which all sorts of hand conditions, trivial and severe, are encountered, it is now unusual to see a patient with lymphangitis who requires hospitalization This is because the resident staff has been instructed to treat every trivial hand injury with respect, and whenever contamination is suspected the patient is given antibiotic therapy at the time the wound is repaired Similarly, physicians who treat minor hand infec-

tions in their offices are to a large extent using antibiotics and the development of lymphangitis is therefore prevented With a severe lymphangitis, the administration of antibiotics together with application of wet dressings, elevation of the extremity and rest will be effective in most cases within 24–48 hours

Lymphangitis is the one condition in which primary surgery should never be done Not only is there no indication for it when no pus is present, but opening of the tissues simply spreads infection into deeper structures

OSTEOMYELITIS AND JOINT INFECTIONS

Osteomyelitis is rarely primary in the hand, usually being caused by infection of the adjacent soft tissues or of a joint The commonest cause of joint infection is a puncture wound over a knuckle, such as that sustained in a fist fight, as soon as the finger is extended, the primary wound is closed and highly virulent organisms are held within the joint The terminal phalanx may be secondarily infected from a felon, and any of the interphalangeal joints can become infected from a tenosynovitis With tenosynovitis, the infection may also enter the epiphysis of the base of the middle phalanx, causing osteomyelitis along this phalanx, and may extend to the next phalanx by crossing the joint

In improperly handled compound fractures and open wounds of the joints due to trauma, osteomyelitis and joint infections are likely to result (Fig 173) The bones of the hand, however, are remarkably resistant to infection when one considers how frequently compound fractures are encountered in the hand and how often they heal without infection

DIAGNOSIS—The diagnosis of infections of the joints and bones of the hands depends more on skilful surgical assessment of the symptoms present than on the x-ray findings X-rays should always be taken, but the degree of demineralization of the bones apparent will frequently lead to a diagnosis of osteomyelitis when such is not actually present Joint infections should be suspected when there are local redness and swelling, together with tenderness around the joint, pain on shoving up on the finger and grating on motion The x-ray appearance here is mostly one of loss of the cartilage and contour A definite sequestrum is rarely formed in the fingers unless there has been a fracture, but loose pieces of bone will at times be found (Fig 174)

TREATMENT—Regardless of the advent of antibiotic and chemotherapy, the general principles of treating bone and joint infections are

still applicable. Some joint infections, if not too severe, may be treated by aspiration and, depending on the organism found on culture, administration of the correct antibiotic This regimen, with immobilization and elevation of the part, may make it possible to avoid the wide incisions formerly thought necessary This method applies to milder forms of infection before complications set in When a joint becomes involved from a puncture wound and the patient is seen within a short time and is hospitalized, the condition may improve rapidly with antibiotic therapy and application of massive hot, wet dressings Usually, however, some permanent changes in the joint will result



FIG 173 *(left)* —Osteomyelitis of terminal phalanx which followed an open fracture.

FIG 174 *(right)* —Septic arthritis of middle metacarpophalangeal joint which followed a puncture wound There is osteomyelitis of the adjacent metacarpal and phalanx with beginning sequestrum formation

In the treatment of primary hematogenous osteomyelitis anywhere in the body, antibiotics find their maximal field of usefulness In the hand, however, where osteomyelitis is usually due to infection of the soft tissues, adequate drainage is required There is no advantage in removing the bone or in curetting, draining, packing open or otherwise disturbing it, although loose pieces of bone should be removed

When draining infected *finger joints,* the surgeon should be mindful of the volar pocket This cannot be reached directly but may be drained adequately through two lateral incisions Joint infections with complicating tenosynovitis end disastrously, the finger almost invariably becoming stiff When such stiffness checks the motion of the other fingers in the hand, it is perhaps better to amputate the involved finger than to risk stiffening of the whole hand This is particularly true of the ring finger This amputation is usually done later, after the patient has had a chance to try the hand If carried out before infection subsides, a guillotine type of amputation through the involved joint should be done

Wrist joint infections are rarely seen even after open wounds due to trauma but were formerly a complication of hand infections which had spread to the radial and ulnar bursae These infections were complicated and difficult to treat The diagnosis rests on tenderness about the circumference of the joint and pain and crepitation on movement; x-rays show loss of cartilage and disintegration of carpals Aspiration of pus from the joint confirms the diagnosis The joints about the wrist, except for the greater multangular metacarpal, pisiform triquetrum and radioulnar joints, all communicate anatomically In suppurative processes the radioulnar joint is quickly invaded However carefully treatment is carried out, considerable disability always results The ulnar approach to the wrist suggested by Bunnell permits free drainage and removal of the infected proximal row of carpal bones A good-sized lateral incision is made, and the flexor and extensor carpi ulnares are severed near their insertions. The joint capsule is opened and the joint is then sprung open by deviating the hand radialward Bunnell recommended removing the distal end of the ulna to allow pronation and supination The hand is immobilized in a plaster of paris cast extending from the necks of the metacarpals to above the elbow.

TETANUS AND GAS GANGRENE

Tetanus

Tetanus infection in hand injuries is the same as tetanus infection elsewhere in the body The incidence is slight in clean, simple wounds, if a wound is adequately debrided and primary healing occurs, there is not much danger of tetanus in the ordinary industrial injury There is danger when the contaminating organism is present in the wound, when the tissues are necrotic or there are foreign bodies, and when the wound is deep so that oxygen is not present Thus, all wounds which cannot be ade-

quately debrided, all complicated wounds with considerable tissue injury, all puncture wounds, all wounds sustained in a barnyard and complicated lacerations sustained on the street do require prophylactic therapy

PROPHYLAXIS †—*Passive immunization* —For wounds seen within 24 hours after injury, the usual dose of tetanus antitoxin is 1,500 units With *coexisting diabetes mellitus or arteriosclerotic peripheral vascular disease*, a large wound or known gross contamination, the recommended dose is 3,000 units For wounds seen after 24 hours, the dosage should be doubled for each day of elapsed time up to a total of 10,000 units When adequate surgical debridement is not possible or the wound does not heal, the period of protection should be prolonged by repeating the 1,500 unit dosage every seven days until the wound is clean or healed An alternate method is to administer a larger dose (up to 100,000 units) initially with the expectation that a longer period (up to three weeks) of protection will be provided

The use of tetanus antitoxin should always be preceded by appropriate tests for sensitivity to horse protein The tetanus antitoxin is diluted 1 10 in saline solution for intracutaneous or ophthalmic testing and only a minute amount of the diluted material put into the eye or skin The skin wheal should be about the size of the head of a pin to avoid false positive reactions Negative responses render immediate serum reactions unlikely but have no value in predicting vulnerability to delayed serum reactions Positive reactions to skin tests, a previous dose of antitoxin or known sensitivity to horse proteins renders serum therapy dangerous When both eye and skin reactions are positive, the danger of anaphylaxis is greater than the hazard of tetanus

It has not been proved that desensitization programs are capable of providing antitoxic immunity In the event that equine antitoxin is contraindicated, bovine antitoxin should be used after appropriate skin tests are carried out with negative results

The incidence and severity of reactions are greatest with intrathecal and intravenous administration of serum and least by the intramuscular route Adequate prophylaxis for serum reactions consists of administration of 0 3 ml of 1 1,000 epinephrine in an oily base immediately before injection of antitoxin, and antihistamine drugs for 10 days Corticotropin is used for treatment of an established serum reaction

Active immunization —There are two programs and two objectives of

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† Based on the report of the American Association for the Surgery of Trauma Committee for the Study of Immunization as Prophylaxis for Tetanus and Gas Gangrene (Champ Lyons, M D , Chairman)

vaccination with toxoid for immunization against tetanus The first is to prepare the patient for use of toxoid in prophylaxis Basic vaccination is carried out with two doses of toxoid given four to six weeks apart and a third dose six to 12 months later, subsequent booster doses are given every four years or at the time of injury The second objective is to provide a sustained immunity for patients (children, farmers, etc) especially prone to tetanus infection of trivial wounds Basic vaccination consists of three doses given at intervals of four weeks with a fourth dose six to 12 months later, subsequent booster doses are given every two years or in the event of a major wound

For the basic vaccination slowly absorbed alum-precipitated toxoid should be used Its combination with either diphtheria toxoid, pertussis vaccine or typhoid vaccine is not only satisfactory but appears to be desirable Booster doses are best given as the more rapidly absorbed fluid toxoid

With a lapse of more than four years after the last booster dose, there is often a delayed or inadequate response to toxoid beyond the four to five day period usually required for the recall of antitoxin antibodies

Prophylaxis with tetanus antitoxin and toxoid—In persons not previously vaccinated with toxoid and receiving tetanus antitoxin, active immunization with toxoid should be started concomitantly because the sensitizing effect of the prophylactic serum renders subsequent antitoxin therapy hazardous and uncertain Toxoid should be 1 ml in quantity, given in a separate syringe and at a separate site The use of toxoid and antitoxin in previously vaccinated persons may be considered when (1) a massively contaminated wound and delayed surgical care make onset of tetanus likely before the four to five days required for response to toxoid, or (2) the lapse of more than four years after the last booster dose produces a situation in which a previously vaccinated patient may require six or more days for response to toxoid

Diagnosis—Tetanus should be suspected whenever a patient with any kind of wound develops trismus and stiff neck. In a typical case, a patient had a sliver removed from her thumb a week previously The original wound was so trivial that tetanus was not suspected even when she made direct complaints about neck and jaw symptoms The length of the incubation period and the distance from the wound to the central nervous system are supposedly related to severity of symptoms

Treatment—A patient with clinical signs of tetanus should be hospitalized immediately and vigorous treatment started The patient is kept in a dark room and all possible stimuli removed Adequate sedation is

necessary but morphine should be avoided The original wound should be excised surgically if possible and left open, local application of zinc peroxide has been recommended Antitetanus serum and penicillin should be given in large quantities In severe systemic tetanus, tracheotomy, continuous curarization and the use of a Drinker respirator may be required

Gas Bacillus Infection

This infection, like tetanus, is one which is apt to occur in crushing injuries or gunshot wounds in which devitalized tissue, foreign bodies and



FIG 174-A —Gas gangrene of hand—a rarity Hand caught in onion-topping machine Although tissues were carefully debrided, the characteristic odorous, bubbly discharge appeared in 48 hours Treated with 40,000,000 units of penicillin daily and wide opening of tissues with eventual recovery

contamination are all present Gas gangrene may occur in complicated forearm wounds but is quite uncommon in injuries of the hand alone (Fig 174-A) The most reliable prophylaxis is early and adequate wound debridement, the wound being left open Several days later, when the wound is clean, it may be closed by delayed suture Prophylactic use of antitoxin is ineffective and is not recommended. Although gas gangrene toxoids show experimental promise, they await clinical evaluation

The symptoms of gas gangrene infection are fairly characteristic. There are a peculiar reddish cyanosis of the extremity and a sickly sweet odor to the wound discharges Crepitation of the tissues is usually apparent on

palpation, but this phenomenon may also occur when air is injected into the tissues in some other way Pain, a rapid pulse and extreme prostration are obvious Finally, clostridia may be demonstrated in smears.

TREATMENT—Once the infection is established, extremely vigorous care is necessary to prevent death Formerly, amputation above the level of the gas was routine, but this is no longer considered necessary for every case If a muscle group is involved, that group of muscles should be excised The wound is then packed open and may be treated with some oxygen-forming chemical such as zinc peroxide The original wound also should be widely excised and packed open Large doses of polyvalent anti-gas bacillus serum are given Chemotherapy and antibiotics are also of value but do not take the place of surgery

CHAPTER THIRTEEN

Secondary Tendon Repairs: Tendon Grafting

MUCH THAT is written about tendon surgery is confusing to the student I must emphasize that primary repairs are much less difficult technically than any type of secondary repair, whether graft, secondary suture or transfer. Secondary procedures are definitely in the field of reconstructive surgery They should be done as elective procedures under optimum surroundings, and the surgeon who undertakes them should have a variety of technics at his command so that he can select the procedure most likely to succeed in a given case Haphazard secondary repairs can do more harm than the original injury

As outlined in Chapter 9, the successful restoration of function depends about half on the technical skill and judgment of the surgeon and half on such things as the type of injury, degree of contamination, and the patient's healing properties and co-operation during convalescence

In general, the favorable locations for secondary repair are the same as those shown in Figure 85 for primary repair or primary repair delayed a few days Under perfect conditions a primary repair or a delayed primary repair *in the palm, wrist, or near the tendon insertion* in a digital tendon is often better than a secondary because of the extreme pathologic changes produced in these regions later by excessive scarring, contracture of muscles and/or degeneration of tendons Delay of more than one month frequently results in tendon degeneration from loss of blood supply and in muscle contracture with limitation of excursion as well as obliteration of tendon channels by excessive proliferation of scar tissue In *the sheath* in no man's land, secondary repairs will often be successful

if the tendons still lie free in the sheath and have been held from retraction by the vincula Cases of this type are naturally a rarity, and usually grafting operations are necessary here

If conditions for a primary repair are not perfect, secondary tendon repair will give much better results than primary There are several advantages in performing a secondary repair a clean field is assured, the operator is relatively sure of the viability of the tissues he is working with, and the proper instruments, assistants, hospital facilities, etc, are available The principal disadvantages are the obliteration by scarring of some of the landmarks and of the channels for the tendons and the retraction of muscles which makes tendon juncture more difficult In addition, there is a tendency for tendon ends to proliferate and for tendons to become attached to their surroundings, whether inside or outside their sheaths Except for these difficulties, the technic of secondary repair does not greatly differ from that of primary repair.

Under optimal conditions, when a primary tendon repair is not done, a period of approximately one month should elapse before secondary repair is undertaken This assumes that the primary wound has healed kindly and completely, that no inflammatory reaction is present and that no tissue is lost When the original injury is accompanied by loss of covering tissues, these must be replaced before tendon repairs are made Customarily the defects are replaced with skin and subcutaneous fat supplied by a flap or tube pedicle (Fig 175), and the tendon repairs carried out after healing is complete

Preparation and anesthesia—The patient should usually be admitted to the hospital the evening before surgery and a thorough preparation of the skin carried out This involves scrubbing the skin of the extremity to the axilla, shaving, cutting the nails short and applying sterile packs to the whole arm Whatever type of anesthesia is elected, it is best to withhold the patient's breakfast and to administer the usual preanesthetic sedation The operating room setup is that described in Chapter 2 The Esmarch bandage and pneumatic cuff are used to obtain the bloodless field which is essential in all the more complicated cases

Incisions—The operator should be thoroughly familiar with the anatomic landmarks of the hand and the various operative approaches, since identification of structures is considerably more difficult after a wound has healed than in a fresh traumatic wound The usual incisions are midlateral on the digits, parallel to the creases in the palm and L-shaped or serpentine in the forearm (see pp 48-52 and Figs 17 and 86) It is best to approach sound tendon proximal and distal to the

scarred area and then to dissect toward the scar When there has been perfect wound healing, flexor tendons will not infrequently be found lying free in their sheaths distal to the point of laceration, and the proximal stump after being found and dissected loose will slide easily down to meet the distal end Sometimes so much proliferation of scar tissue from

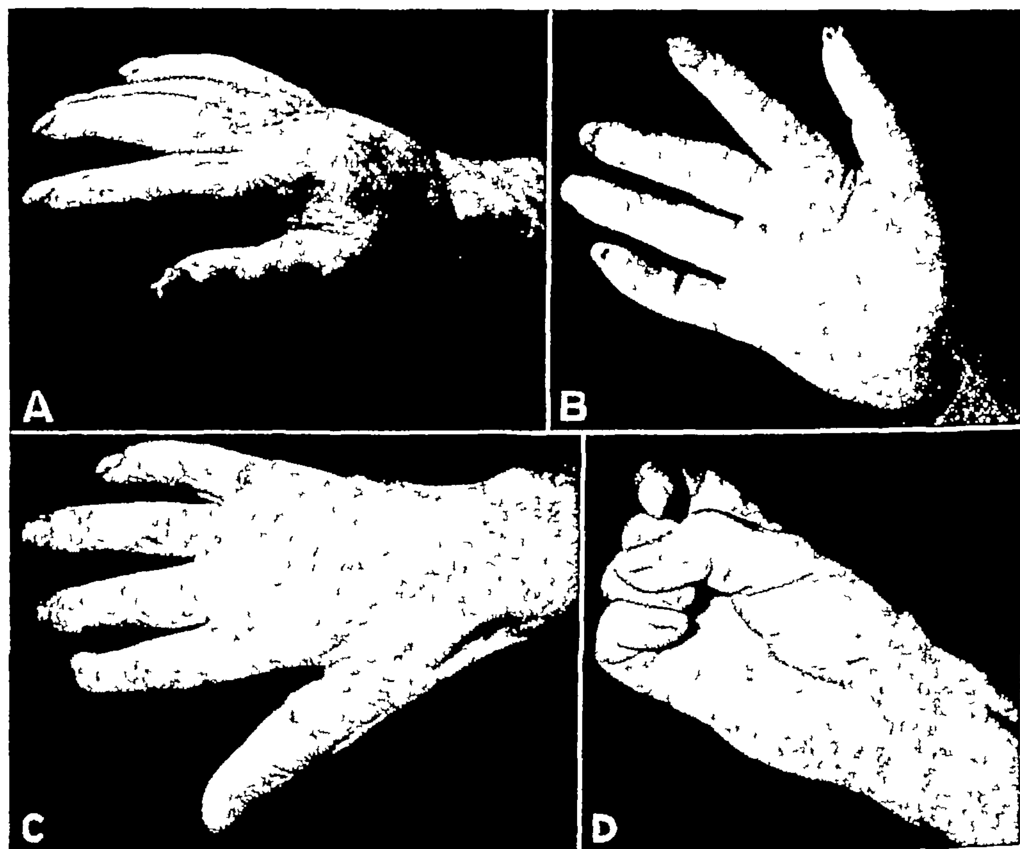


FIG 175 —Repair of deep saw cut of hand which traversed dorsum, destroying metacarpophalangeal joints, all extensor tendons, the flexor tendon and digital nerves of index finger and the thumb web Banjo splint had been used and all digits were completely stiff and the hand functionless when the patient was first seen (*A* and *B*) Repair in stages dorsum was resurfaced using the pedicle method and extra pedicle was used to lengthen thumb web, metacarpophalangeal joints were arthrodesed in position of function and tendon grafts used for all extensors and flexor of index finger, nerves also repaired *C* and *D*, end result.

the epitenon and tendon sheath occurs that the landmarks may be difficult to establish without wide dissection Normal tissues are protected while the scar is excised and parts of the tendon sheath and scarred tendon removed with it The distal end of the tendon is easier to recover than the proximal end, which may have retracted into the carpal canal or the fore-

arm In the palm or finger the lumbrical muscle usually prevents the profundus tendon from retracting too high, and the sublimis will present itself after the profundus is located The flexor tendon of the thumb almost invariably retracts up into the forearm In the wrist the distal end of the tendon becomes attached to the transverse carpal ligament and the proximal end retracts into the forearm. In repairs here, the carpal canal may have to be opened, preferably through a lateral approach as described in Chapter 9.

PRINCIPLES OF REPAIR—Wound healing in secondary tendon repairs is similar to that in primary repairs except that absence of the original trauma, of potential infection and of possible devitalized tissue renders the procedure more certain in its outcome In the palm and forearm, end-to-end tendon junctures are usually possible if carried out *within two months* before the muscle has contracted excessively. Under the carpal ligament and in the ensheathed portion of flexor tendons in the digits some repairs will be quite successful provided the sheath and tendon were not originally severely damaged and the operator makes a correct repair. Usually in these locations a graft is more desirable Whenever a secondary repair is made it should be as simple as possible and everything possible should be done to allow for sliding For this reason, in the digit only one tendon—the profundus—should be repaired, and under the carpal ligaments a few tendons can be repaired but not the whole set.

Extensor tendons, when repaired secondarily, can be expected to recover function more readily than flexor tendons The reasons for this are the same as those previously given under primary repairs If checkreining is present, simple excision of the damaged tendon may result in adequate function

TECHNICS

The operator must methodically dissect out all the damaged parts, identify them and match them before undertaking repair. There is always some proliferation from tendon ends both proximally and distally and this scar tissue must be removed The best results will be obtained when an anatomic restoration is effected in areas where adhesions will not prevent function After making the necessary dissection, the surgeon decides whether he will be able to suture the tendon ends together or must use some substitution An example of a substitution method is illustrated in Figure 176

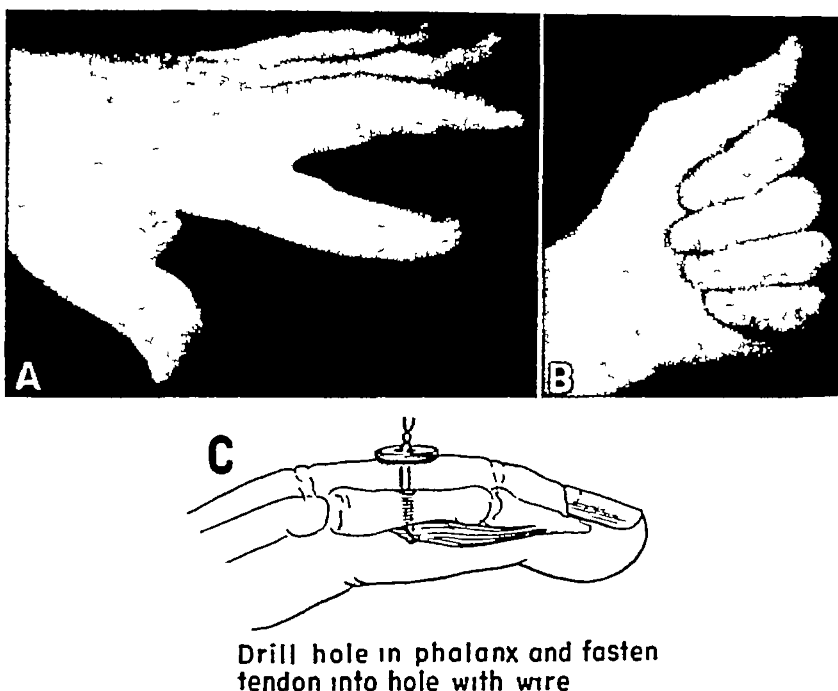


FIG 176 —*A* and *B*, results of repair when sublimis function is normal and profundus cannot be repaired *C*, technic distal stump of profundus tendon is tenodesed to phalanx to hold distal joint in slight flexion Removable loop of wire holds tendon in hole drilled in phalanx

END-TO-END SUTURE

The simplest repair is end-to-end tendon suture (Figs 177 and 178), and the fact that all the structures involved are viable makes it more attractive to the occasional operator than the more complicated tendon grafting or tendon transfer The end results within tendon sheaths are often poor and the judgment required to determine whether the simpler or the more complicated procedure will be successful is not a faculty which can be acquired by reading a text Suggestions only can be given and not arbitrary rules The problem is an equation involving wound healing, the location of the repair, the patient's intelligence, age and tendency to joint stiffening, and the capabilities and experience of the surgeon

If excessive tension is necessary to make a tendon juncture in secondary tendon repairs, the result will probably not be too successful. This factor is more important when the loss of tendon length is due to part of the tendon being missing than when it is due to contraction of the muscles If much of the tendon is missing and the proximal end is forcibly drawn

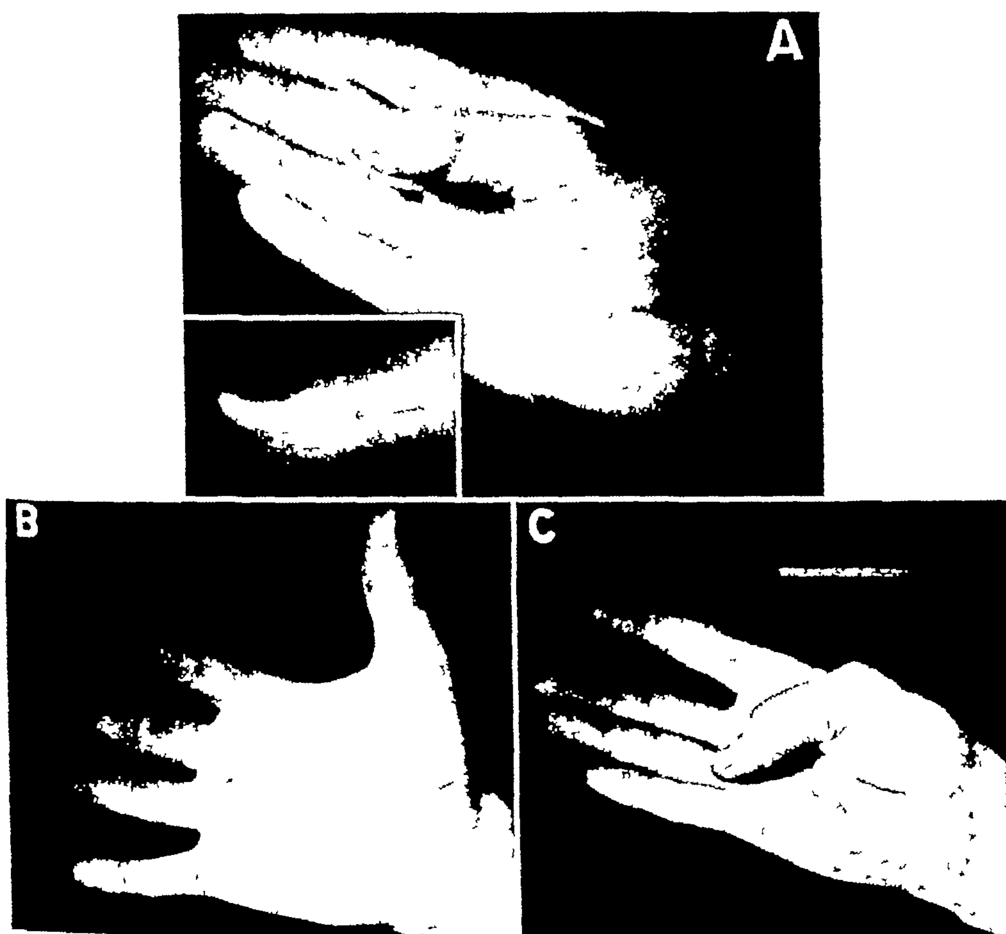


FIG 177 —Saw cut of thumb which severed digital nerve and flexor tendon treated primarily by simple wound closure and splinting One month later tendon and nerve repair was done, with the defect in phalanx covered with flap of tendon sheath and fat. *A*, original wound healing, and x-ray showing bone defect *B* and *C*, function five months later Primary repair is contraindicated in this situation

down and joined to the distal stump, the intermuscular digitations between the fingers will be affected and the other fingers will not flex well even if the damaged finger does move The sacrifice of much more than ½ in of tendon length is not crippling at all in some patients but in others throws the hand out of balance In patients with incipient Dupuytren's disease, even when the hand is not thrown out of balance, a severe contracture sometimes develops all along the soft tissue of the volar surface of the injured digit This is a most distressing and irreparable calamity Whenever the tendon or muscle proximally has a poor excursion due to scarring as well as to contracture, the result of a simple tendon repair is apt to be poor Under any of these circumstances a tendon graft or substitution is, in the long run, a better operation.

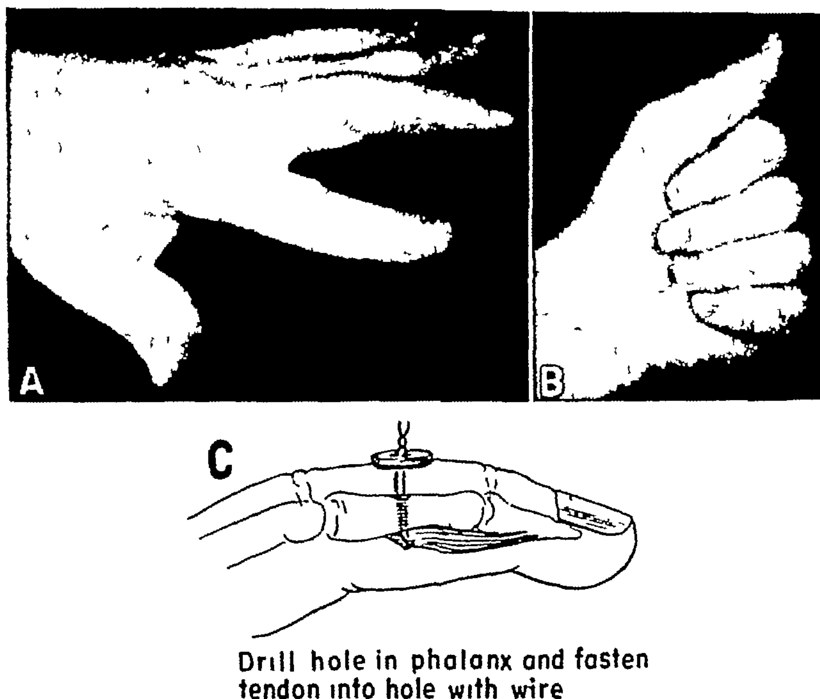


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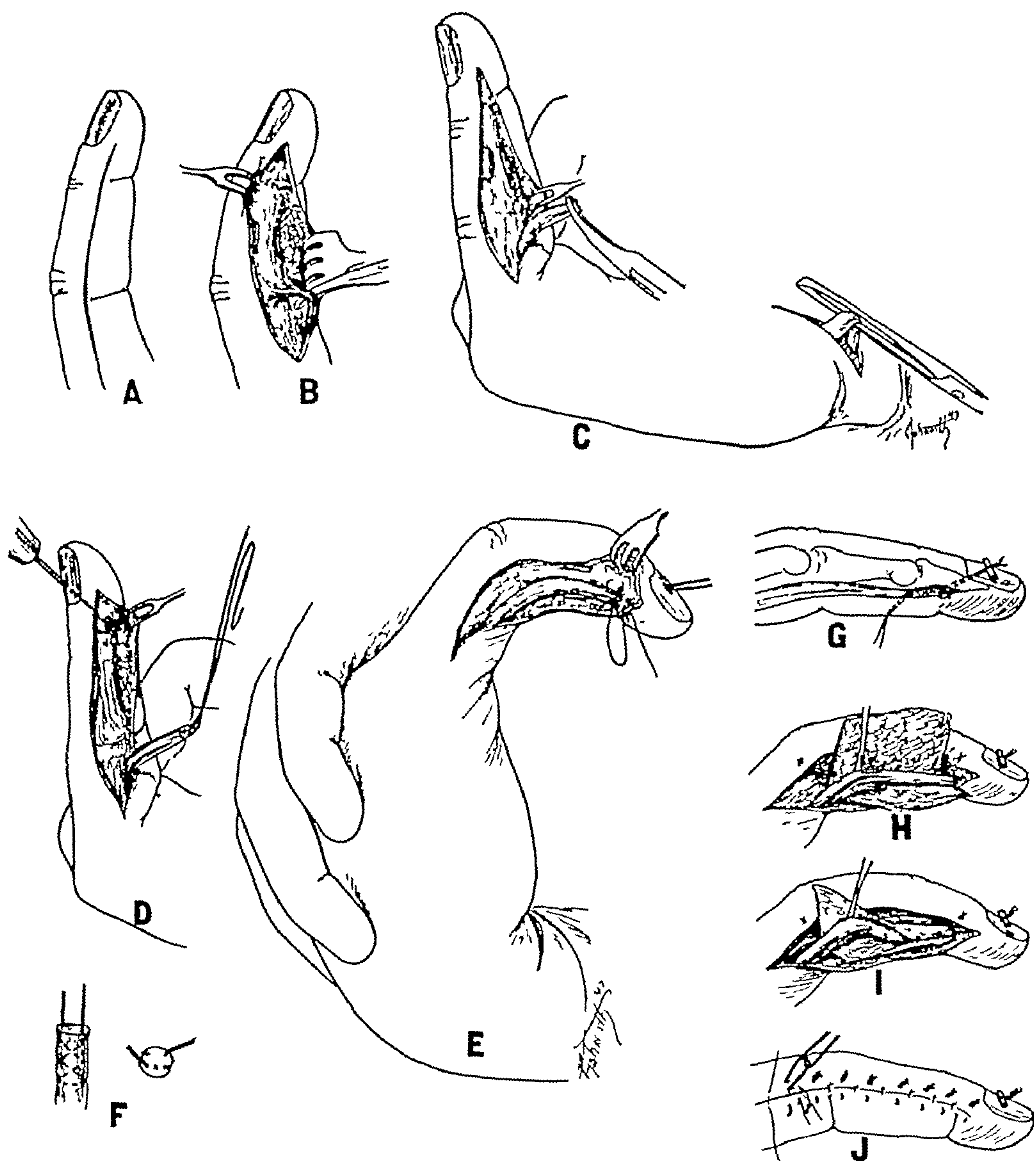


FIG 179 —Technic of tendon advance (secondary tendon repair) *A–C,* dissection of scar tissue *A,* incision, *B,* tendon identified, *C,* a supplementary incision in palm or wrist may be necessary to make sure the tendon is free *D–F,* tendon suture *D,* suture inserted and phalanx drilled, *E,* flexing of wrist and finger to advance tendon which is then anchored to applicator on dorsum of nail, *F,* technic of inserting suture when pull-out wire is not used *G–J,* wound closure *G,* completed repair, pull-out wire comes out through midlateral plane of finger, *H,* and *I,* areolar tissue may be used around tendon in scarred area (note suture used to prevent sliding), *J,* skin closed with mattress and tack sutures (Modified from Nichols Ann Surg 129 223-234, 1949 ,

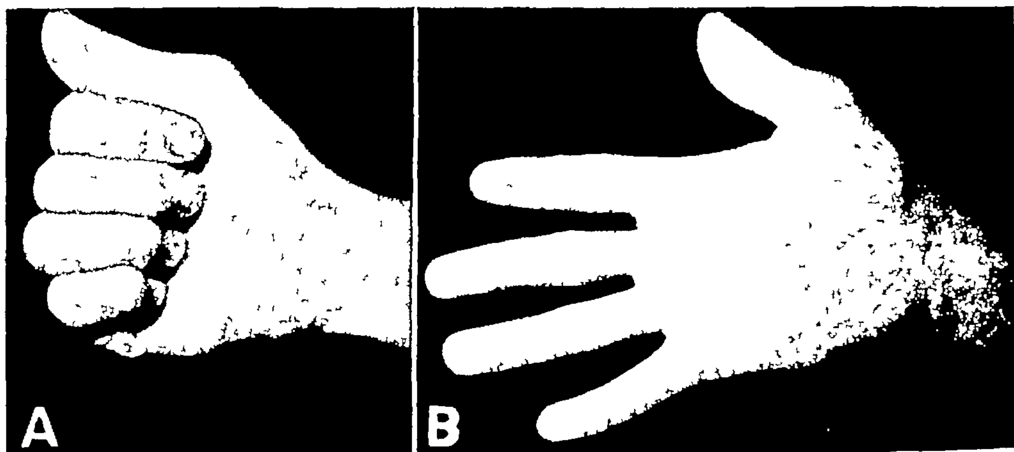


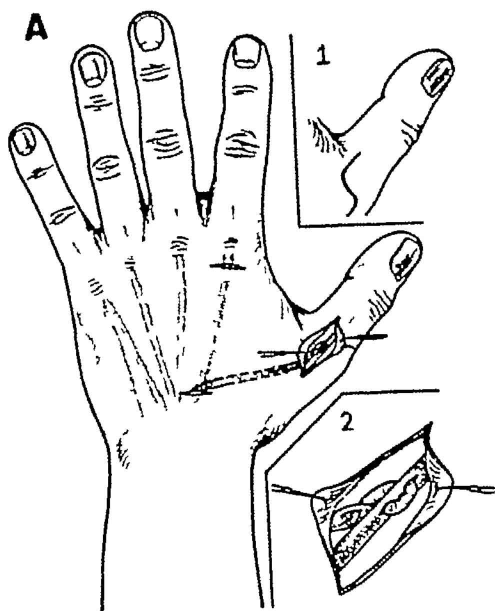
FIG 178 —Diagonal laceration of middle segment of index finger with severed profundus tendon repaired two months after injury *A* and *B*, flexion and extension two months postoperatively

Secondary repairs of flexor tendons are more successful in the palm, wrist and middle segment of the finger or thumb than in no man's land In no man's land tendon grafting is usually necessary

In the proximal interphalangeal joint area there is a space ½–¾ in long in which there are actually three tendons—two slips of sublimis and one profundus Incidence of tendon injury in this area is high. Secondary repairs here will often be successful, as the injury usually occurs when the fingers are flexed, and the level of severance with the finger extended actually lies opposite the middle phalanx, with the profundus severed distal to the sublimis When this injury occurs the strong vinculum at the middle joint frequently prevents excessive retraction of both tendons Sometimes the best results will be obtained by repairing *both* the profundus and sublimis tendons according to the technic shown in Figure 105

Tendon Advance

This simple method of tendon repair which may be used occasionally avoids the difficulties of either graft or end-to-end suture In this procedure the proximal tendon stump is brought down and sutured to the distal stump close to its insertion, the tendon between the point of laceration and the distal digital crease being excised This maneuver places the tendon juncture at the distal crease where no motion is needed and avoids the scarred area where adhesions are sure to form Tendon advancing is not successful if there is excessive tension (Figs 179–181)



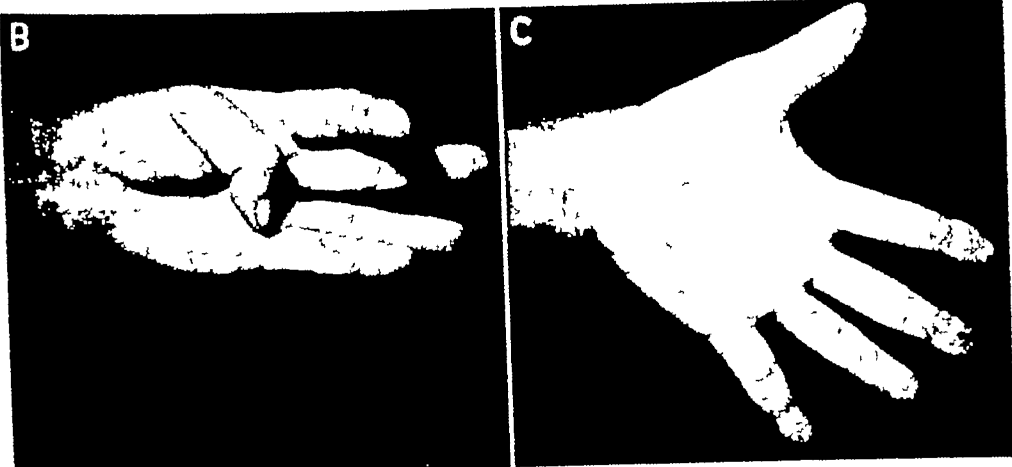


FIG 182—*A*, technic of tendon transfer for loss of extension of thumb Through three short incisions, made as illustrated, the extensor indicis proprius is detached at its insertion, withdrawn at the wrist and rerouted and attached to the thumb extensor *(A, 2)* *B* and *C*, illustrative case showing postoperative flexion and extension.

Other substitutions which give good results are the sublimis of the index or ring fingers to take the place of the long flexor of the thumb, the sublimis of a longer finger to take the place of a profundus of a shorter one or, occasionally, the sublimis to take the place of a profundus in the same finger The last procedure is rarely possible since it requires a normal, full length sublimis tendon with a badly damaged profundus tendon severed in the proximal segment of the finger

Transferring of tendons on the volar side of the hand has the advan-

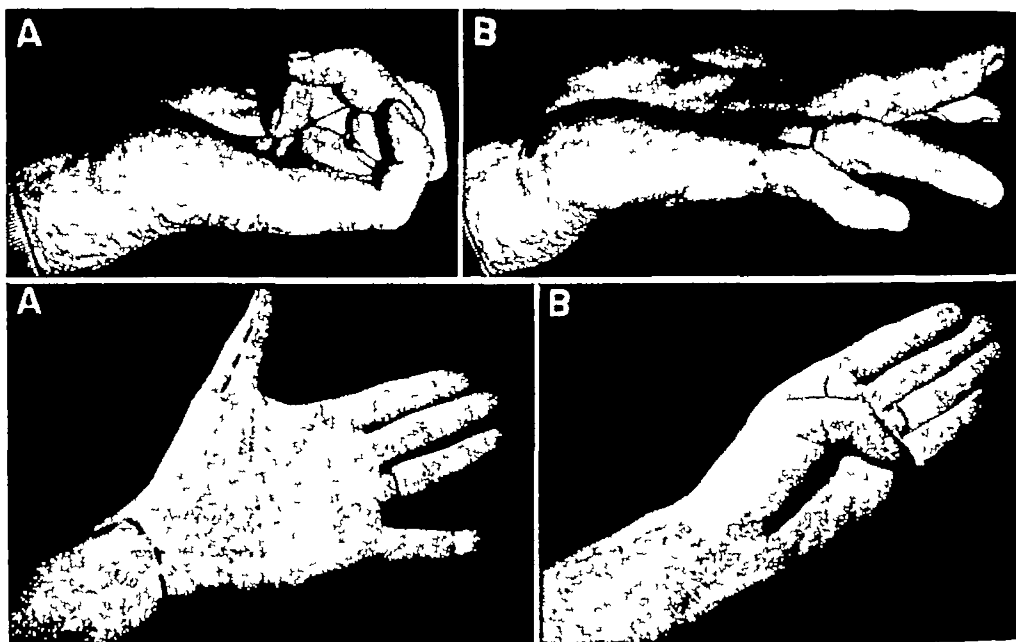
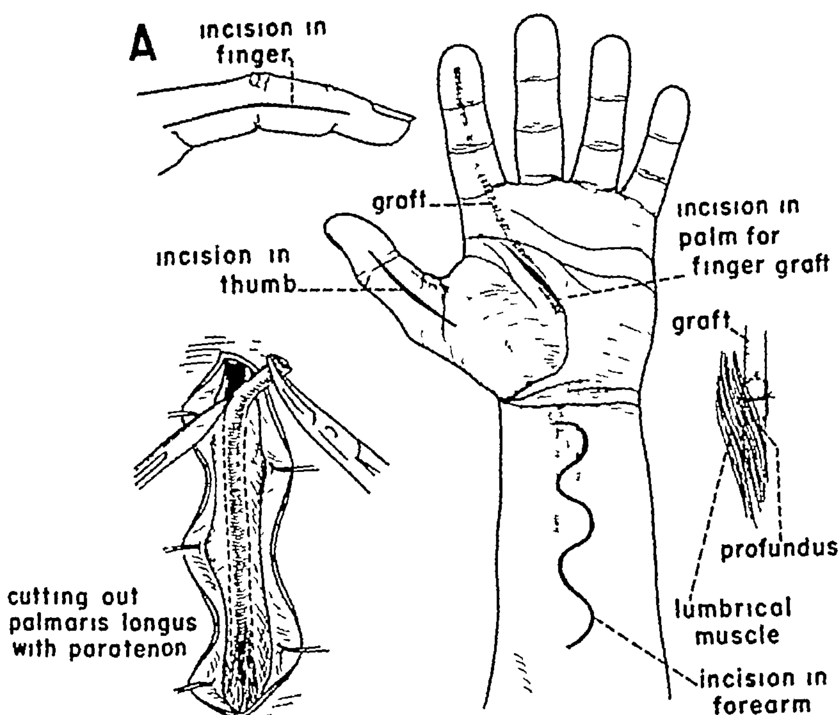


FIG 180 *(above)* —Result of tendon advance procedure on long finger (technic in Fig 179) *A,* full flexion, and *B,* slight loss of extension when wrist is also extended

FIG 181 *(below)* —Result of tendon advance in thumb in secondary repair of rip saw injury which lacerated palmar surface and severed digital nerve and tendon. *A,* extension and *B,* flexion, dotted lines indicate operative scars (From Nichols Ann Surg. 129 223-234, 1949)

Tendon Transfers

If a tendon substitution can be done which will give a good result immediately to the injured digit and will cause no loss of function in the other digits, this method is probably to be preferred It is especially desirable when the original musculotendinous unit proximal to the tendon lesion is of poor quality The best example of this procedure is the use of the extensor indicis proprius as a substitute for the long extensor of the thumb (Fig 182) When properly done, the patient regains full use of the thumb and is never aware that a substitution has been made The extensor indicis proprius is detached at its insertion through a ½ in transverse incision and is withdrawn down the back of the hand to the spot where it emerges from under the dorsal carpal ligament It is then rerouted and fastened into the long extensor of the thumb just proximal to the metacarpophalangeal joint A buttonhole or interweaving technic is used to make the tendon juncture and by actual measurement exactly the same tension as was originally present is maintained



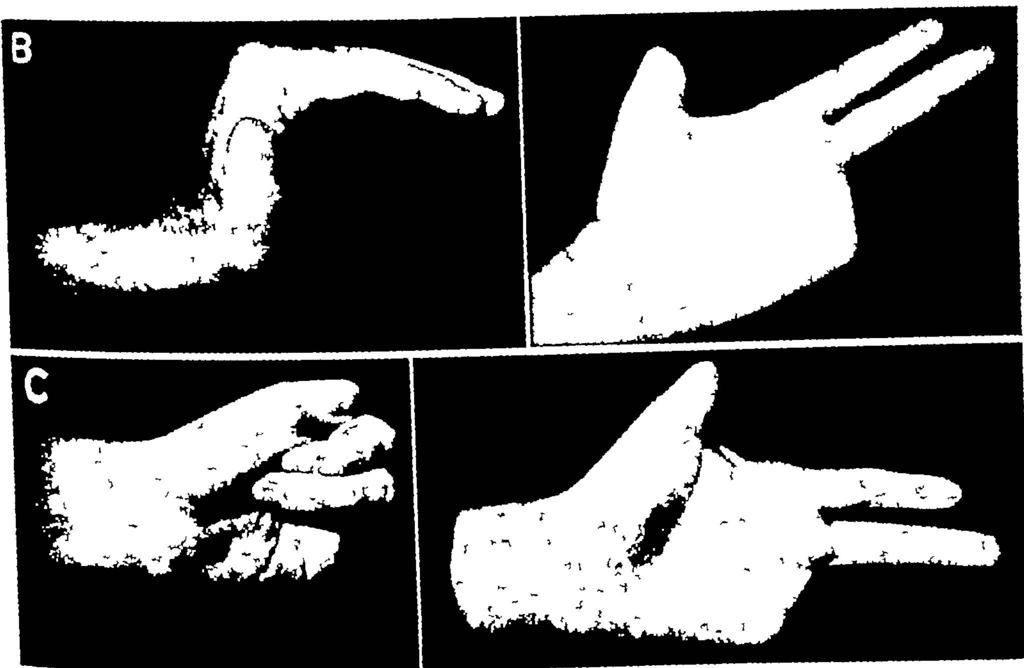


FIG 184 —*A*, technic of tendon graft using index finger as example (see Fig 179 for detail of distal tendon suture) For the thumb, the graft is run from the wrist to the distal phalanx *B* and *C*, sawmill injury with loss of end of thumb and fourth and fifth digits and severance of tendons and nerves in remaining fingers at proximal finger crease *B*, maximal flexion and extension before repair, no pinch, grasp or sensation In repair, extensors of amputated fingers were used for flexor tendon grafts and nerves were sutured *C*, after repair digits touch palm forcibly, have full extension and good sensation

tage that only one tendon juncture is necessary and this is located in an area near the insertion of the tendon where slipping is not necessary. However, disturbances in the blood supply of the transferred tendon often cause it to become swollen and adherent within its new sheath, giving no improvement in function

Tendon Excision

Simplification of a previous tendon repair will frequently result in improved function The sublimis tendon, for example, may be checkreining the finger If this tendon is excised and the profundus tendon freed, much better function will be obtained (Fig 183) A similar situation may exist in the wrist after attempted repairs in the carpal canal

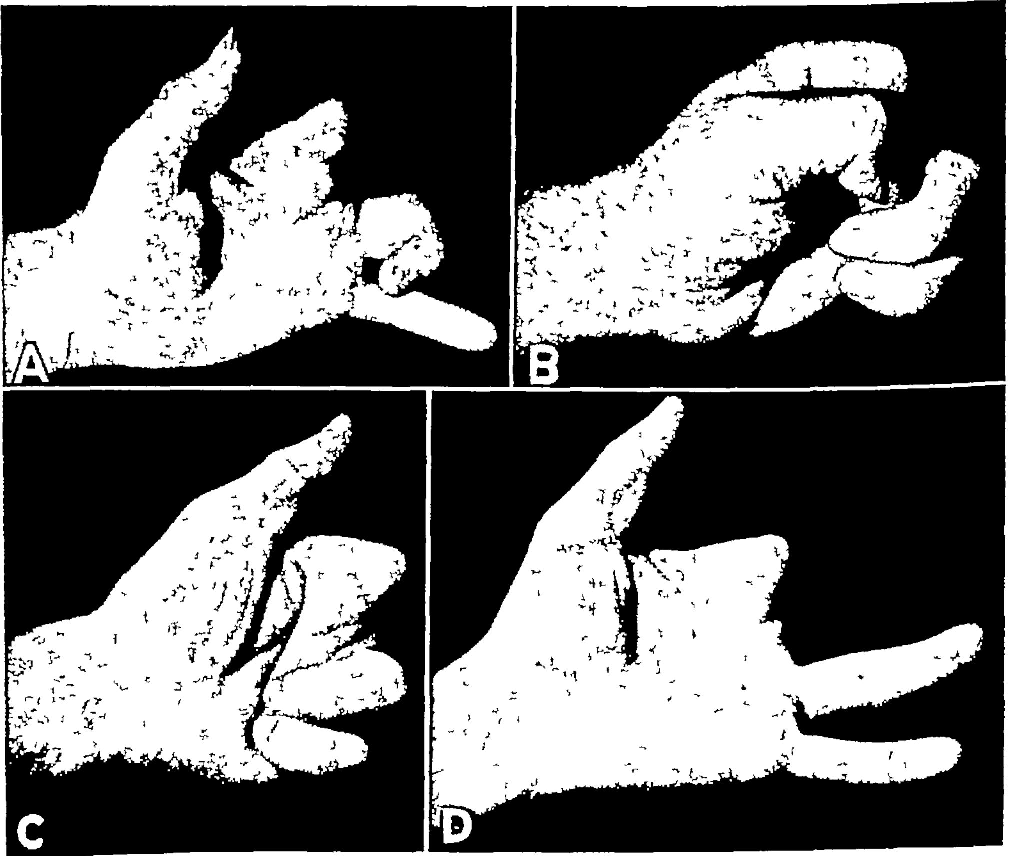


Fig 183 —Sawmill accident severed index and long fingers and damaged palm, injuring tendons and nerves of ring finger *A* and *B*, resulting contracture Scar in palm and damaged sublimis tendon were removed, and nerve was transferred from one of amputated fingers to radial side of ring finger to replace lost nerve *C* and *D*, after excision of sublimis, full flexion and extension were obtained

should be cut out, leaving the paratenon around it, and not jerked out leaving it bare * The distal juncture of the graft should always be made as close to the insertion of the tendon as possible and the proximal juncture should be placed where adhesions will give no trouble In the palm of the hand it is customary to use the origin of the lumbrical muscle as the site of the proximal tendon juncture A stitch or two in the lumbrical muscle is then used to surround the tendon juncture When the long flexor of the thumb is to be replaced, the graft should run all the way from the low forearm to the distal phalanx (Fig 185) The long extensor of the thumb can be successfully replaced with a graft which runs from the musculotendinous junction on the dorsum of the forearm to about the middle of the anatomic snuffbox (Fig 186) Other grafts for the exten-

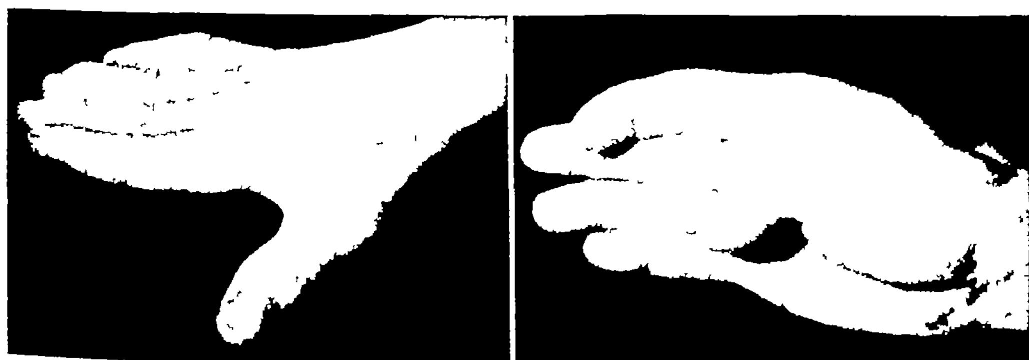


FIG 186—Full function obtained after repair of extensor pollicis longus with tendon graft taken from foot

sors of the digits are rarely necessary, tendon transfers being extremely easy to carry out on the dorsum of the hand

A great many rules have been set up to guide the operator in deciding how long a tendon graft should be The simplest rule is to use the length which will permit approximately normal function of the digit along with its mates when the wrist is flexed and extended after the operation is completed It is much better for a tendon graft to be just a little tight than too loose This is especially important when contractures of the muscle have occurred If it is possible to measure the length of the damaged tendon accurately, the graft should be the same length as the pieces of tendon removed

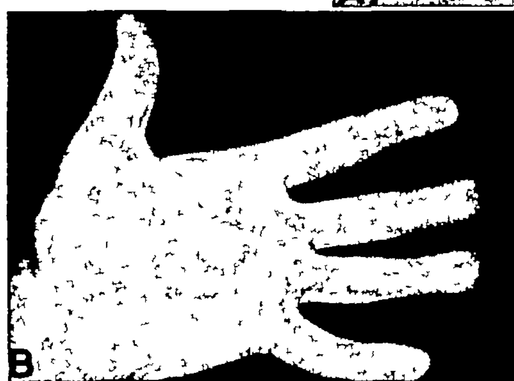
The tendon graft may be joined to the stump of the tendon proximally either by end-to-end suture of the core type or by interweaving Usually the graft is smaller than the stumps of the tendon to which it is attached, and for this reason I prefer to mortise the tendon ends together (Fig 187,

* Excessive paratenon should, however, be avoided

Tendon Grafts

Under most circumstances tendon grafts will be required whenever tendon ends cannot be brought together easily, and they should preferably be used whenever tendons are to be joined within their sheaths (see Fig. 85) The graft most often used is the palmaris longus, although extensor tendons of the toes as well as the plantaris tendon are available and some surgeons use fascia lata Although sublimis tendons have been used for





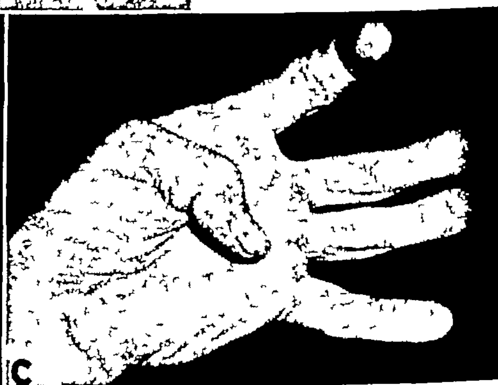


Fig 185—Long diagonal saw cut of thumb, with severed flexor pollicis longus and some loss of skin, treated by simple closure of original laceration *(A)*, followed by secondary tendon grafting two months later *B* and *C*, end result.

grafts, surrounding them with additional paratenon grafts where they run through the digital sheaths, most sublimis tendons are rather thick and are slow to vascularize A thin tendon such as the palmaris longus is better If a rather thick sublimis tendon, such as that of the long finger, is used and is to be inserted in a smaller finger, it should be split and only about one-half used for the graft Since revascularization must take place, the tendon graft should never be surrounded by any type of foreign matter

The technic of tendon grafting is illustrated in Figure 184 The graft

should be cut out, leaving the paratenon around it, and not jerked out leaving it bare * The distal juncture of the graft should always be made as close to the insertion of the tendon as possible and the proximal juncture should be placed where adhesions will give no trouble In the palm of the hand it is customary to use the origin of the lumbrical muscle as the site of the proximal tendon juncture A stitch or two in the lumbrical muscle is then used to surround the tendon juncture When the long flexor of the thumb is to be replaced, the graft should run all the way from the low forearm to the distal phalanx (Fig 185) The long extensor of the thumb can be successfully replaced with a graft which runs from the musculotendinous junction on the dorsum of the forearm to about the middle of the anatomic snuffbox (Fig 186) Other grafts for the exten-

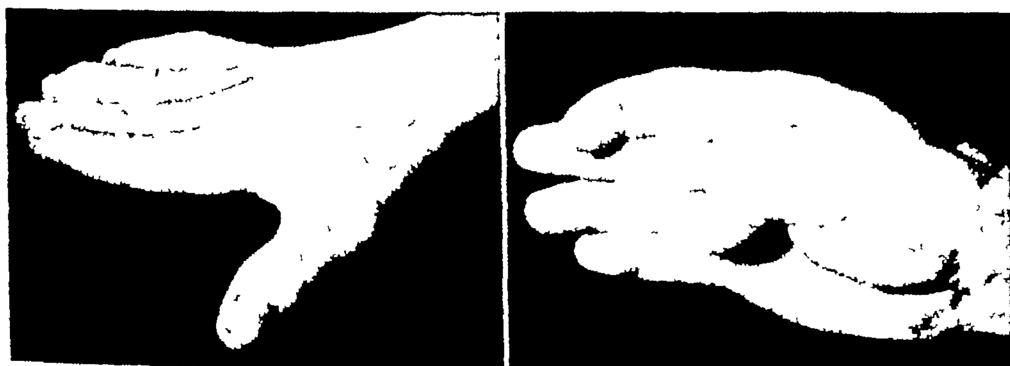


FIG 186—Full function obtained after repair of extensor pollicis longus with tendon graft taken from foot.

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* Excessive paratenon should, however, be avoided

A and *B*). Distally the graft can be fastened to the stump of the old tendon at its insertion, using the pull-out wire technic, or it can be fastened directly to the bone In attaching the tendon to the bone, the phalanx is drilled obliquely from the proximal end of the nail to the site of the old tendon insertion The graft is then tucked into the site of the old tendon and held by a wire passed through the drill hole in the phalanx An additional suture or two fastens the remnants of the old tendon around the insertion of the graft So many methods of making the distal tendon junc-

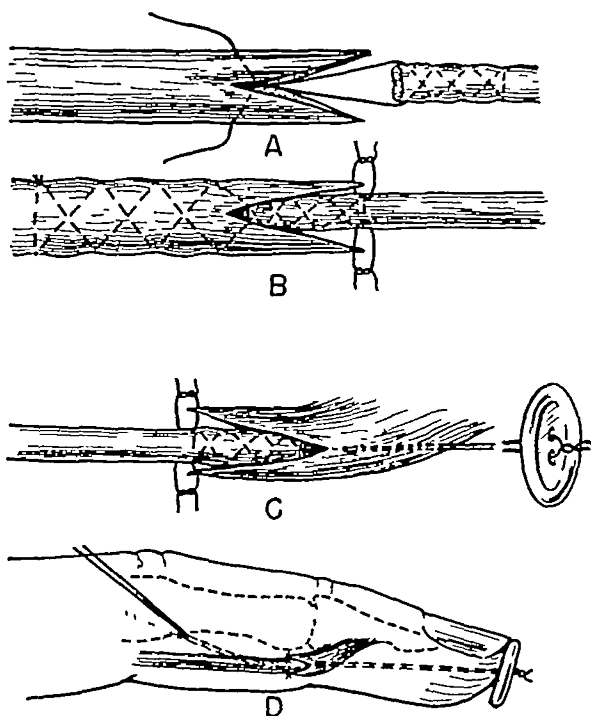


FIG 187 —Mortise method of joining tendon ends when graft is much smaller than recipient tendon *A* and *B*, method in palm or wrist, *C* and *D*, method at finger end, using pull-out wire Edges of larger tendon should be sutured all around graft.

ture are available that selection is largely a matter of the operator's preference When an adequate amount of normal profundus tendon remains attached to the insertion distally, I prefer to make this tendon juncture by mortising the tendon ends together (Fig 187, *C* and *D*). This method is slightly more complicated but seems to give better results

Usually the tendon sheaths in the fingers are excised except for a ring about ⅛ in wide in the proximal phalangeal area

Postoperative care after tendon grafting is exactly like that of any other tendon operation Perfect healing of the wound must be achieved or failure of the operation is almost inevitable The extremity should be splinted

to release the pull on the tendon juncture and should be kept elevated to prevent swelling The patient should always be given antibiotics. Skin sutures are removed after about 10 days and the splinting and pull-out wires after about three weeks Active exercises are then begun and must be intelligently persisted in for months if good results are to be obtained. The question of whether motion should be started at an earlier date is

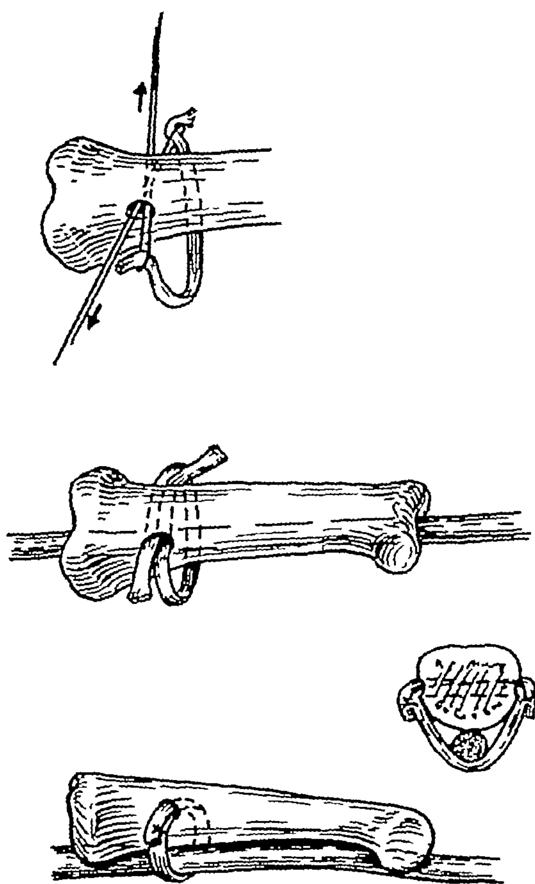


FIG 188—Formation of pulley by passing tendon slip through drill holes in proximal phalanx

still *sub judice* If motion is started early and the tendon junctures or graft do not separate or break, and if an inflammatory reaction does not occur causing extra fibrosis, then the extremity at times seems to have a more rapid and complete return of function On the other hand, more complications are encountered when early motion is used There is greater delay in wound healing, more grafts are broken, more tendon junctures separate and frequently an inflammatory reaction sets in around the proximal tendon juncture which eventuates in binding adhesions Since the

graft must obtain a new blood supply from the surrounding tissues it seems logical to immobilize long enough for this to occur

FORMATION OF PULLEY—Whenever flexor tendon grafts are created the surgeon is faced with the problem of supporting the new tendon to prevent bowstring deformity If an intact portion of the original sheath is available over the proximal phalanx, a section of it not over ¼ in long should be preserved without disturbing it The rest of the sheath should be excised or, if necessary, turned down to cover any bare bone left in dissection Often an impromptu pulley or sling can be fashioned by drawing a slip of a sublimis tendon or a remnant of the sheath across the new tendon graft A pulley should never be tight, and if the original

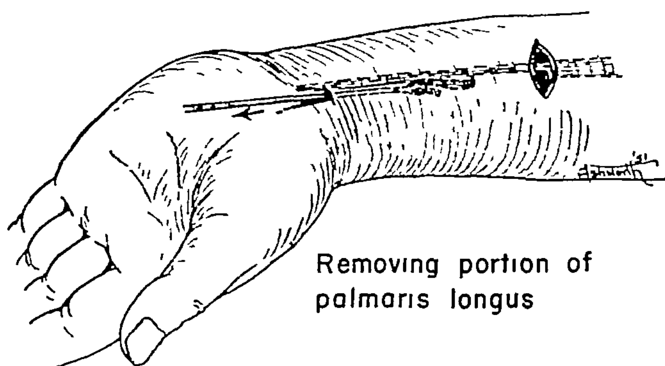


FIG 189—Technic of obtaining graft for repair of extensor tendon insertions Two short transverse incisions are made, a probe is inserted through the wrist incision, threaded with a split piece of the palmaris longus and then withdrawn.

sheath is too shrunken it should be elongated by sectioning it obliquely and swinging this piece to a transverse position

A pulley is not the *sine qua non* to good function in a flexor tendon graft in a finger and is rarely needed in the thumb Badly scarred digits rarely need pulleys, and in fact a transverse scar often acts as a pulley Boyes of Los Angeles uses a buried suture to form a sling of subcutaneous tissue in a similar way I think that free-grafted pulleys tend to interfere with tendon graft motion if they are inserted at the same time as the graft and prefer to insert them later if tendon bowing becomes a problem A ⅛ in hole is drilled through the base of the proximal phalanx and the graft passed through it Both ends of the sling tendon are passed through the phalanx and heal almost immediately (Fig 188).

REPAIR OF EXTENSOR TENDON INSERTIONS IN FINGERS—As described previously, the weakest areas in the extensor apparatus are over the interphalangeal joints Rupture of the extensor tendon over the distal

joint produces a mallet finger, and rupture over the proximal interphalangeal joint produces a buttonhole deformity of the tendon with loss of extension of this joint and hyperextension of the distal joint The treatment of these conditions differs for old and recent injuries. For fresh injuries, the simplest methods available often give good results; these have

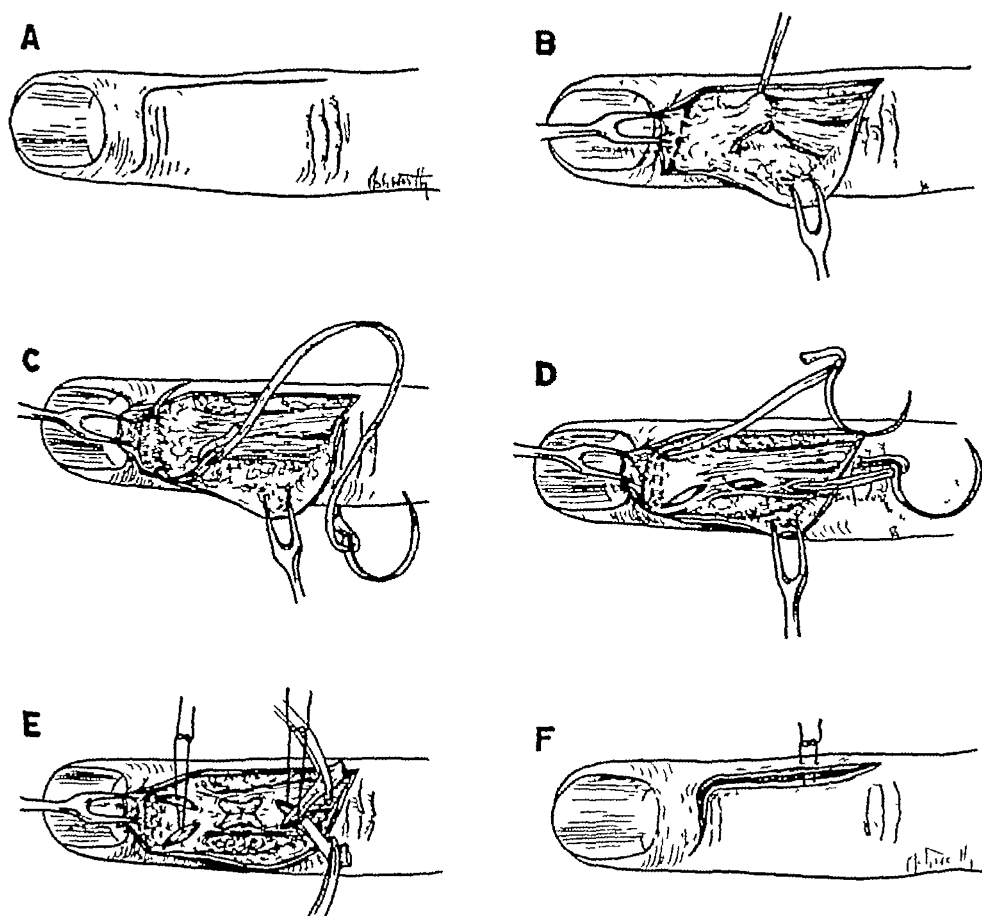


FIG 190—Operation for correction of mallet finger *A*, incision, *B*, flaps retracted and scarred tendon identified, *C*, tendon graft anchored distally into dense tissue on dorsum of proximal end of phalanx, *D* and *E*, graft woven into sound tendon proximal to scar and fastened in place, *F*, illustrating half-buried mattress suture used for wound closure (From Nichols J Bone & Joint Surg 33-A 836-841, 1951)

been discussed in Chapter 9. If primary treatment is not successful, or if the patient is seen too late, a reconstructive procedure is necessary to correct the deformity

The principle of the reconstructive technic to be described is the use of a tendon graft which is anchored where the tendon is fairly strong and bridges the weak area where ordinary sutures would tear out The primary wound must heal soundly, and an interval of about one month

must therefore be allowed before repair can be undertaken If infection has occurred, a longer waiting period is necessary.

The tendon graft consists of a split portion of the palmaris longus approximately 3 or 4 in long and about the thickness of no. 1 catgut. It is removed through two short transverse incisions made over the tendon on the anterior aspect of the forearm and wrist (Fig 189) The tendon is identified and a probe passed alongside it As much of the tendon as is needed for the suture is transected at the upper end, fastened to the probe and withdrawn through the wrist incision. The tendon may usually be split without withdrawing its whole thickness outside the skin The graft is threaded onto a small curved needle *

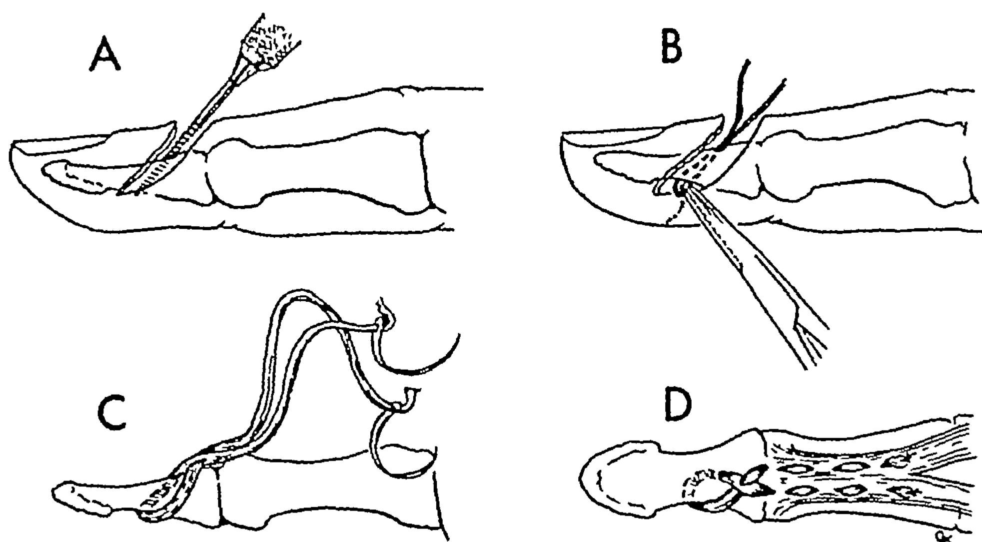


FIG 191 —Alternative method when tendon is fastened to drill hole in bone (Modification of operation shown in Fig 190)

The usual minute attention to technic is essential in this procedure (Figs 190–193) General anesthesia is preferable, and the operation should be done in a bloodless field with the use of a pneumatic tourniquet Skin flaps must be widely reflected and great care exercised to avoid injury to the skin or underlying tendon The nail bed on the dorsum of the distal phalanx must be protected The dense tissue just distal to the dorsal articulating lip usually affords a good anchor for the graft.

The tendon graft is first anchored at the insertion, being passed through a hole in the phalanx Both ends of the graft are woven into good tendon, and the tension is adjusted in such a way that the joints are flexed to the

* The needle used is a Murphy's hemostatic (Ironarm no 834), a small round needle, fully curved, with a heavy body, trocar point and a big eye

same degree as those of the fingers on each side when the wrist is flexed and extended The graft is then sutured into place with mattress sutures of fine wire It is not usually necessary to remove the scar tissue which has filled in the gap caused by the injury, but one should free the tendon from its surroundings It is important to obtain the correct degree of tension over either joint, so that the finger may flex and extend properly and the graft will not tear loose later

If the skin over the dorsal area is too thin to heal soundly, a flap from the lateral aspect may be rotated onto the dorsum of the finger to cover the tendon graft, the donor area being covered with a skin graft This

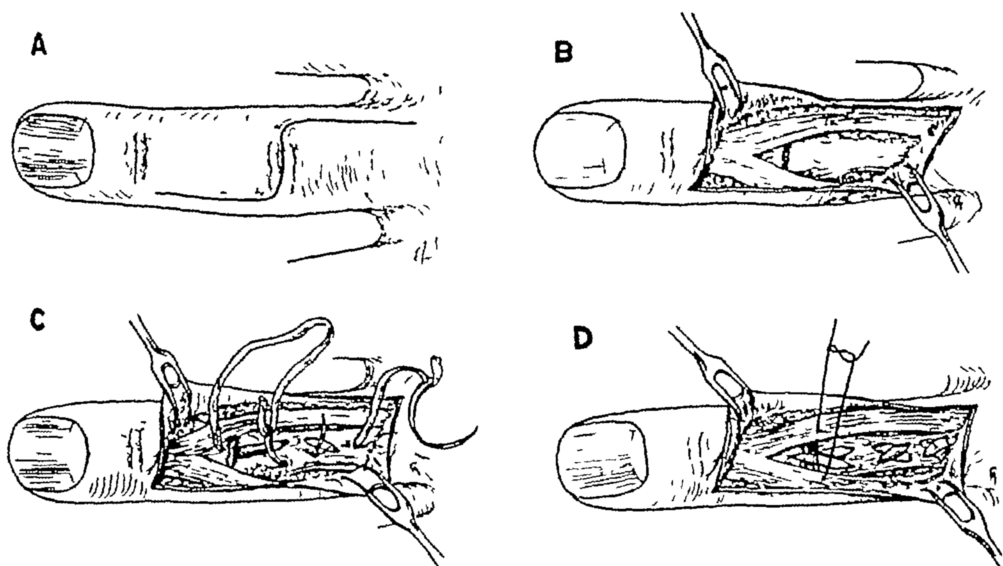


FIG 192—Repair of central slip over proximal interphalangeal joint *A*, incision, *B*, flaps retracted, *C*, insertion of graft; *D*, position of tendon after grafting A single suture is used for triangular ligament. (From Nichols J Bone & Joint Surg 33-A 836-841, 1951)

procedure may also be necessary when the dorsal skin is badly torn by the primary injury The lateral bands around the middle joint may have to be freed from the sides of the joint, and the triangular ligament may have to be repaired by a suture These bands should not be sutured together directly over the joint, as this will interfere with flexion

After adequate hemostasis, the skin should be closed, preferably with half-buried mattress sutures (Fig 190, *F*) Splinting is essential in order to relax the repaired tendon. After the mallet-finger operation splinting should be applied to relax the pull on the tendon The cast shown in Figure 95, *B*, the splinting in *C*, or the transfixion pin, *E*, may be used, depending on the operator's preference For tendon repairs over the proximal interphalangeal joint, the volar plaster splint which holds the wrist

and the finger in extension is used Either of these casts should be left on for about three weeks

This method is particularly suitable in cases in which there are no other defects, the affected finger has good joints and skin and normal sensation and the intrinsic muscles are functioning normally.

PALM, WRIST, FOREARM AND DORSUM OF HAND—Most secondary repairs in the palm are the result of failed primary repairs For these cases the tendon-grafting procedure described before is indicated Occasionally one encounters a case in which primary repair in the palm failed because of inadequate suture, with tendon separation If good tendons are still present in wrist and fingers, secondary suture with excision of scar

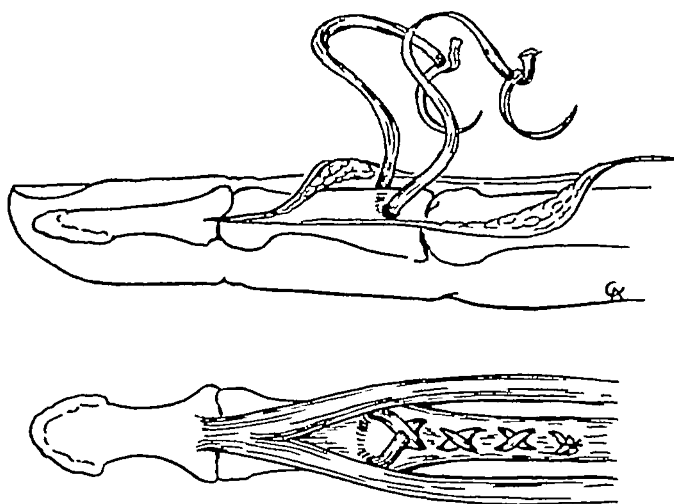


FIG 193—Alternative method when tendon is fastened to drill hole in bone (Modification of operation shown in Fig 192)

tissue may be adequate If, due to infection or burn, no good tendon is found, insertion of grafts extending from the forearm to the finger ends, using toe extensors as donor tendons, may be indicated These procedures are exceedingly difficult, and the results are usually not very gratifying

Tendon grafts on either surface of the forearm or on the dorsum of the hand work well Figure 194 shows a method that has been used successfully to supply extension to the fingers Wrist extensors or flexors can be replaced with grafts, which are usually passed through an abbreviated portion of the original pulley, most of the pulley is excised, as in flexor tendon grafting

Before a graft is used in these areas a tendon transfer should be considered Often secondary myostatic contracture has rendered the original muscles unfit for return to duty

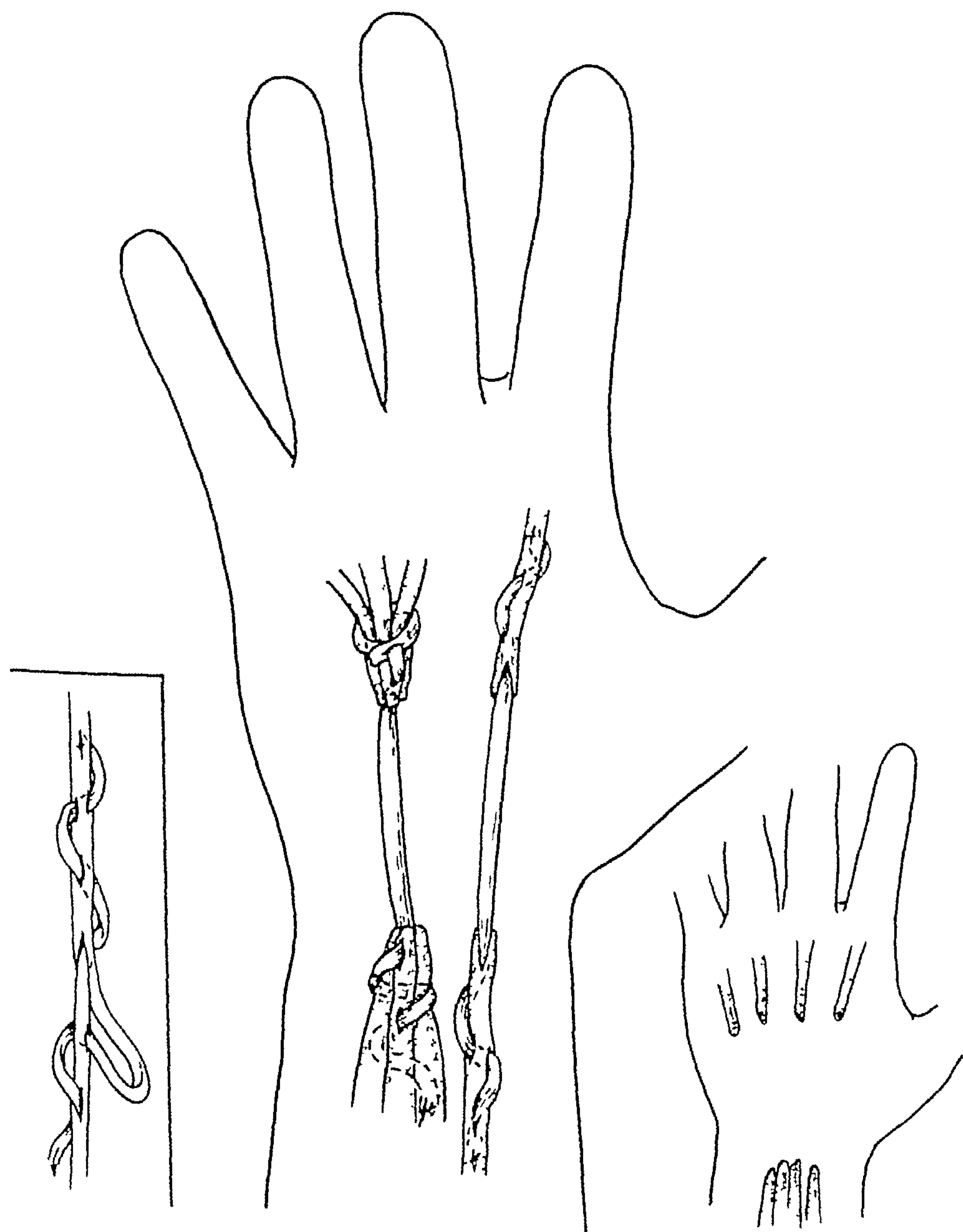


FIG 194—Graft to extensors one tendon graft from extensor communis to third, fourth and fifth digits, one graft from extensor indicis proprius to index finger *Inset,* technic for interweaving tendon ends

CHAPTER FOURTEEN

Elective and Reconstructive Procedures

DEGENERATIVE DISEASES OF PERITENDINOUS TISSUES

GANGLION

THE SURGEON who treats hand injuries will rather frequently encounter tumors and cysts of the hand Of these, by far the commonest is the ganglion A ganglion is a single or multilocular cyst with a connective tissue wall and a lining of flat, undifferentiated cells The cyst is usually flat in contour and is attached by a rather broad base to the underlying joint capsule or tendon sheath A direct communication with the joint or with the synovial lining of the sheath is sometimes present

About 50 per cent of patients will give a history of trauma preceding development of the ganglion The commonest locations of ganglions on the hand are (1) on the dorsal surface of the wrist, where they arise from the joint capsule over the carpal bones, (2) on the volar surface of the wrist, where they arise over the distal end of the radius and lie beneath the radial artery and between the adjacent tendons of the flexor carpi radialis and supinator longus, (3) over the volar surface of the proximal segments of the fingers where they arise from the flexor tendon sheath, and (4) over the dorsum of the hand in the metacarpal region or the dorsum of the fingers

DIAGNOSIS—The diagnosis is usually not difficult In general, symptoms are slight pain, soreness and weakness in the adjacent joint and a tendency to easy fatigue of the extremity If dorsally located, the affected wrist becomes sore if the hand is used in pushing On the volar surface

of the wrist, pain radiates along the path of the radial artery. In this location the artery is lifted up by the ganglion and may appear to be a small aneurysm On the volar surface of the fingers, a tender mass which interferes with grasping may be present before the ganglion becomes large enough to be visible Over the dorsum of the fingers, tenderness is often complained of and the finger with the ganglion seems to get bumped most often

The diagnosis of ganglion rests on the exclusion of other tumors, the history and symptoms The tumor may be so hard and the swelling so firm and apparently fixed that an x-ray will be needed to rule out the possibility of bone tumor According to Dudley, the method of diagnosis is analogous to that used by the surgeon in diagnosing appendicitis For example, if an otherwise healthy young adult has pain in the abdomen with vomiting and soreness in the usual location, the diagnosis is probably appendicitis. Similarly, if an otherwise healthy adult has a slightly



FIG 195 —Ganglion. Typical appearance on back of wrist

tender tumor on the hand in one of the usual locations, it is probably a ganglion (Fig 195).

TREATMENT —*Nonoperative* —In the past, the treatment of ganglion was not satisfactory and a number of indirect methods were used in an attempt to avoid surgery. One of these is the time-honored method of subcutaneous rupture Properly carried out, this is done not by striking the ganglion with a book but by the surgeon making firm pressure over the ganglion with both thumbs while holding the affected joint in the position which makes the ganglion most prominent When this method is successful, the ganglion will be felt to collapse suddenly with a peculiar crepitant sensation, and when the pressure is removed the swelling is gone. Pressure dressings are then applied and the joint immobilized for about a week Although this method saves the patient from an operation, a disadvantage is the high rate of recurrence. Frequently, even though the swelling does not return, the symptoms remain Also, subsequent opera-

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wrist, since the patient is more comfortable with the wrist splinted If careful, adequate surgery is carried out, recurrences will be few

QUERVAIN'S DISEASE

Stenosing tenovaginitis of the common sheaths of the extensor pollicis brevis and the abductor pollicis longus was first described by de Quervain in 1895 The relation of this condition to trauma is not satisfactorily explained The rather sharp angulation of the tendon when the wrist is moved with the thumb pinching results in a tenovaginitis which soon becomes stenosing The change primarily involves the fibrous wall rather than the lining of the tendon sheath and always occurs where the tendon passes through a fibrous ring or pulley At times the condition develops after a blow or strain. In one of my patients, a man with a fracture of the navicular, the condition developed within a month after removal of the cast Because of their more limber joints, women are more apt to have the disease Symptoms include pain and soreness which gradually develop in the region of the radial styloid and radiate up the arm and down into the hand and pain or pinching, especially with the wrist dorsiflexed The patient usually cannot get the thumb into the "hitch-hiker's" position without pain Tenderness is present over the tendon sheath and there is often a definite palpable tumor Crepitation usually does not occur

Stenosing tenovaginitis is closely related to trigger finger and has been reported in other tendons about the wrist, where the symptoms are about the same as Quervain's disease but less distinctive, because the thumb is not involved except as in trigger thumb

TREATMENT—Treatment is usually surgical A few mild cases will subside if the wrist and thumb are immobilized in a neutral position which avoids angulation of the tendon sheath, the cast must be left on about a month Operative treatment is less time consuming and gives almost uniform success if properly carried out Local anesthesia may be used

An incision should be made over the affected tendon sheath Many operators make a linear incision in the skin along the axis of the sheath, when this wound heals, a contracting scar occasionally results This can usually be avoided by use of serpentine incisions The sensory branch of the radial nerve lies beneath the deep fascia over the tendon sheath in this region It should be identified and retracted The sheath should then be split open throughout its length and a probe run along to see if any residual constrictions are present above or below the operative site When

tive procedures are made more difficult Most ganglions successfully treated by this method would probably have disappeared spontaneously

A second method involves needling the ganglion and either breaking up the cyst wall by multiple needle punctures or obliterating the cavity by injecting sclerosing solutions This procedure may also be carried out as an office procedure and is occasionally successful but usually is followed by recurrence The sclerosing solutions are apt to cause a violent reaction, and some serious complications have followed their use If treatment of this type is carried out, it is best limited to simple aspiration of the cyst with a large-bore needle

Surgical—When surgery is carried out, complete extirpation of the ganglion and of the ganglion-forming tissue is necessary for success If only the ganglion cyst is removed the recurrence rate averages about 35 per cent By removing not only the dome of the ganglion but the surrounding tissue like the brim of the hat, Bunnell obtained a high proportion of cures This operation of necessity must be done with adequate facilities, and a bloodless field obtained by use of Esmarch's bandage and a tourniquet is essential The incision should be placed so as to avoid contractures On the dorsum of the wrist a transverse or serpentine incision is desirable, on the volar surface of the wrist an L-shaped incision is used On the volar surface of the fingers, a transverse incision in the proximal finger crease can be used if care is taken to avoid the nerves and retraction is carefully done On the dorsum of the fingers a zigzag type or a simple dorsolateral incision may be adequate The ganglion will usually be seen pushing up under the tendons in the wrist The tendons must be retracted and the part of the mesotendon which is attached to the surface of the ganglion must be cut away from the tendon After all the surface attachments are divided, the ganglion will be seen to arise from a rather broad pedicle This entire structure must be removed, taking a part of the dorsal joint capsule, annular ligament and tendon sheaths with it Frequently, small cysts are encountered in the surrounding tissue The wrist joint may be opened during this procedure The important thing is to remove not only all the ganglion but all the ganglion-forming tissue as well If the ganglion is ruptured early during the removal, it usually means that dissection has been incomplete and recurrence will take place

After the ganglion is removed, the tourniquet is released, the bleeders tied and the wound closed If the joint capsule has been opened it is best closed by suture and the wrist positioned by cast to maintain closure without tension Usually one layer of sutures in the skin is adequate A compression dressing and a splint should be applied to immobilize the

the finger is flexed the nodule slips outside the proximal pulley of the tendon sheath and locks the finger in this position The patient cannot then actively extend the finger This condition frequently affects the thumbs of persons who work in canning factories where thousands of cans a day bump against the tendons Sometimes acute trauma may be causative In one instance, an amateur fisherman's ring finger became affected following a day of salmon fishing, he had worn a ring, against which the handle of the rod pounded all day In a few instances more than one digit may be involved, and in some occupational conditions both hands are affected alike

Snapping finger also results when the aponeurosis of the extensor mechanism is damaged over the metacarpal head, allowing the extensor tendon to slip off the head into the space between the fingers This type usually does not cause locking and is not very disabling Sometimes the lateral bands of the extensor mechanism, in passing around the middle joint of the finger, slip off the sides of the joint owing to a tear in the triangular membrane This condition produces more soreness in the joint than trigger finger and may cause some loss of extension and some snapping, but it is not usually confused with trigger finger

Pathologically, the classic type of trigger finger shows a cicatricial thickening of the annular ligament at its proximal end The tendon is smooth, white and glistening, and there is a fusiform nodular enlargement in the tendon itself Either or both tendons may be involved in the finger, in the thumb the long flexor alone is affected In some cases a mild degree of tenosynovitis occurs, with increased vascularity of the tendon and precipitation of protein products The process may involve several tendons at once

DIAGNOSIS —In a patient with a trigger finger, palpation in the palm just proximal to the metacarpal head will reveal a discrete nodule which slides back and forth under the examiner's finger as the affected digit is flexed and extended Some tenderness and pain occur during examination A history of locking of the finger in the flexed position is characteristic and feeling the nodule simply confirms the diagnosis When there is an abnormality of the extensor apparatus, the slipping off of the extensor tendon can be both seen and felt over the dorsum of the metacarpal or the proximal interphalangeal joint

TREATMENT —The largest proportion of cases involve the flexor mechanism Occasionally the condition will subside spontaneously, and in acute cases splinting of the affected digit for two weeks or so, removing any rings or other irritative factors, may be helpful However, surgical

the sheath is opened, instead of a smooth, shiny white tendon with a scanty amount of clear synovial fluid, there will be found a lusterless, reddish, swollen tendon with an abundance of yellowish, turbid synovial fluid The sheath is thickened and shows similar changes which sometimes look almost like granulation tissue, there being increased vascularity and cellular infiltration

The tendon sheath should not be closed by suture. In operating on two patients with recurrent Quervain's disease, I found the sheath completely grown together without any evidence of its ever having been opened. Postoperatively, a few days of splinting will add to the patient's comfort and speed wound healing

Aberrant Tendon

Symptoms exactly like those of Quervain's disease arise when an aberrant tendon is present in the common sheath with the extensor brevis and abductor longus In some cases a tenosynovitis develops, giving rise to the usual pathology of Quervain's disease In others there are symptoms of pain and weakness in the thumb, usually of long duration, although no tenosynovitis is found Sometimes the diagnosis can be established preoperatively, the extra tendon or tendons actually being seen or felt. Quite often these patients will have some other abnormality in the bone and joint structure of the thumb The condition may be unilateral or bilateral The odd tendon usually has a separate muscle slip which is part of the abductor longus, the insertion is usually into the transverse carpal ligament or one of the carpal bones These patients, therefore, often have muscle cramps because the excursion of this tendon differs in amplitude from that of the abductor longus Whenever the condition is suspected and the symptoms warrant, operation should be done After the sheath is split as in the standard Quervain operation, the small aberrant tendon or tendons will be found They should be removed and the tendon sheath left open An aberrant tendon should probably be removed whenever it is found complicating Quervain's disease

Trigger Finger

In trigger finger there is a snapping sensation when the finger is flexed and, if the condition is severe, the finger becomes locked in the flexed position This phenomenon usually results from trauma, although the pathology varies In most cases a nodular swelling forms within the ensheathed portion of the flexor tendons near the metacarpal head When

diately after the injury This palsy often clears up partially or completely several months later, with or without operative treatment Seemingly, cases due to Colles' fracture have a better ultimate prognosis than those due to dislocations of the carpus, although age and severity of the injury are also factors

In cases with an obscure origin, the condition advances so unobtrusively that the patient often comes for treatment after months or years of complaints Diagnosis of these cases is often difficult and may be missed because the attending physician is not cognizant of the lesion Besides varying degrees of numbness confined to the median area and associated motor weakness in the abductor and opponens muscles, there is usually a positive Tinel's sign over the carpal ligament, and if the patient flexes the wrist completely for 30 to 60 seconds numbness, tingling and pain in the median area increase

In the early stage, patients often complain of waking "numbness" The symptoms are worse after a night's sleep, presumably because of swelling of the hands or faulty position during the night An axial x-ray view of the carpal canal may occasionally show some bony defect

Treatment is surgical correction obtained by division of the transverse carpal ligament The procedure is comparatively simple, and if it is correctly done convalescence is brief and there are no ill effects The technical details of this procedure are elective and vary widely from clinic to clinic Some surgeons do a neurolysis of the median nerve I prefer a simpler procedure Two incisions, each about 1 in long are made, one along the flexion crease of the wrist and the other along the thenar crease in the palm The skin is undermined between these incisions and a blunt dissector passed beneath the ligament from the wrist to the palm The ligament is than divided completely, protecting the structures beneath Any bleeders are tied and the skin closed General anesthesia is usually used

The results of this procedure are sufficiently gratifying to justify its use as a routine Most patients feel subjectively better long before the objective signs of median palsy begin to dissipate Complete recovery in old cases is rare

TARDY ULNAR PARALYSIS

Not infrequently symptoms of ulnar nerve paralysis develop many years after injury The patients complain of trouble with the hand, at times without remembering distinctly the elbow injury Usually examina-

alleviation is usually necessary The operative procedure, when properly carried out, is quite simple and the results dramatic and gratifying to the patient In the palm a transverse incision in the region of the distal palmar crease will give adequate exposure The annular ligament is exposed and the nodule on the tendon demonstrated by flexing the finger The annular ligament is then divided laterally on one or both sides for a distance of about ½ in, testing the finger by running the tendon back and forth until no constriction is felt In the thumb the incision can be made parallel to the proximal flexion crease over the metacarpal head In any case, injury to the digital nerves should be avoided

When snapping finger is due to involvement of the extensor mechanism, the appropriate treatment is either to expose the dorsum of the middle joint and suture the triangular ligament with a mattress suture or to expose the aponeurosis over the metacarpophalangeal joint and lash the tendon back to its lateral attachment with a strip of fascia lata Most patients do not find the condition sufficiently disabling to accept surgery Splinting is only temporarily successful, on return to work the symptoms recur

Occasionally trigger finger may be due to an incomplete severance of a sublimis or profundus tendon The tendon proliferates, forming a knob, and symptoms are similar to those from stenosis of a sheath Treatment involves slitting the sheath and removing the nodular enlargement of the tendon and the tendon fibers proximal to it back into the palm

NERVE COMPRESSION SYNDROMES

Carpal Tunnel Syndrome

Median nerve neuritis due to compression in the carpal tunnel of the sensory and motor components of the median nerve is commonly called carpal tunnel syndrome The apparent cause of this condition is often a direct or indirect injury such as dislocation of the lunate or a Colles fracture Some cases have been traced to bony deformity from arthritis, acromegaly, etc Some authorities have noted a thickening of the synovial membrane In any case the most pronounced compression usually comes at the proximal third of the transverse carpal ligament where a transition in the thickness of the ligament occurs Flexion of the wrist and fingers squeezes the nerve between the ligament and the tendons here

Signs and symptoms of the condition vary In cases of obvious traumatic origin there are varying degrees of sensory and motor palsy imme-

PLASTIC PROCEDURES ON STUMPS

After the emergency repair of a traumatically amputated digit (Chapter 4), most workmen will be able to resume their occupations without further surgery. In a small proportion (probably not over 10 per cent of those properly treated primarily), some additional surgery will be necessary to make the remainder of the digit more useful. For the most part, corrective surgery is required because of infection of the primary wound, which causes excessive scarring, loss of skin and eventual contraction of the scar, leading to excessive sensitiveness. In other cases, a primary skin graft may leave the end of the finger inadequately padded or poorly shaped. Sometimes stiffening occurs in healing and eventually the patient decides to get rid of the digit because it is in the way. Success in primary amputations is not always possible, it depends on the severity of the trauma as well as on the resistance of the host and the virulence of the possible infection. This does not mean, however, that one should not adhere to the original rule laid down for amputations—in primary amputations everything should be done to maintain length and to secure primary wound healing with early return to function.

In an elective amputation the function of the hand can be more carefully evaluated than in emergency amputations. If the primary functions of the hand—pinch, grasp, touch and hook—are remembered, it is easier to decide what to do. The thumb is the most important element, the equivalent of one side of a pair of pliers. The index and middle fingers are the most important fingers because of their strength, tactile elements and proximity to the thumb. The ring and little fingers are weaker and have poorer sensation but they aid in holding larger objects and in dexterity.

The individual elements of the fingers should next be assessed: the skin, bone, joints, nerves, tendons and circulation. The skin is most important in that if it is missing or inadequate, the amputation will be functionally unsuccessful. In most healed fingers an appearance of inadequate skin coverage will be found to be due to heavy scarring. Even if there is some loss of skin in the original injury, proper closure of the wound by grafting will usually give a satisfactory result. When excessive scarring has occurred, further amputation may be needed to give an adequate stump.

The bones of the amputated digit may be too long or, if the joints are stiff, the finger may be in the way. In the long and ring fingers, particularly if amputation is carried out by disarticulation at the proximal inter-

tion will show some bony deformity at the elbow due to an old fracture with malunion or a growth disturbance from an injury in youth. Sometimes the original injury was apparently trivial, although usually a definite history can be obtained. Loss of sensation and motor function gradually develop, and the patient becomes quite handicapped

DIAGNOSIS—A history of gradually developing ulnar nerve palsy with characteristic atrophy of the interosseus muscles and loss of sensation of the little finger and half the ring finger is quite diagnostic. The patient is unable to flex the proximal and distal joints of the ring and little fingers, to abduct and adduct the fingers when they are extended, to adduct the thumb or to oppose the little finger or tense the flexor carpi ulnaris The atrophy of the hand may not be noticeable in *mild cases* and the only symptom then may be some tingling or awkwardness One of my patients, a pianist, first noted some difficulty in playing certain selections and later noted a twinge of pain when the elbow was extended and certain chords struck In *severe cases* muscle atrophy gives the hand a striking appearance Loss of pinch and inability to pick up small objects are complained of Ridging of the little fingernail and ulceration of the fingertip may be apparent. Tinel's sign is positive just proximal to the ulnar notch

TREATMENT—The nerve is exposed through a 3 in incision over the region of the median epicondyle It is very important to carefully strip the twigs of the nerve which supply the flexor carpi ulnaris, flexor digitorum profundus and the elbow joint In rerouting the nerve it should be run subcutaneously in such a location that flexion and extension of the elbow will not cause it to snap back and forth. Attempts to fasten it in place with a sling or suture have not, in my experience, been satisfactory, although a stitch or two between the subcutaneous fascia and deep fascia will prevent it from dropping back in a notch immediately after the procedure The nerve can be transplanted beneath the flexor carpi ulnaris muscle, which should then be detached from its fascial origin on the ulna The nerve should not be run through a cut in the muscle, as the muscle cells will then invade the nerve and strangle it The extremity should be splinted until the wound is healed

Recovery after a late, complete ulnar nerve palsy is less apt to be satisfactory than after an early, partial one Motor function of the proximally supplied muscles in the forearm is better than those in the hand Trophic disturbances disappear with a return of sensation, although during the period of return the complaints may actually become more severe

Ideal Amputation

The ideal amputation provides adequate padding, a rounded appearance, a normal range of motion of the joints proximal to it and good sensation When a joint must be sacrificed to obtain this ideal, it is often better to effect some compromise than to sacrifice the hooking action and dexterity of the joint This is particularly true of the distal joint

Ideally, a palmar flap should be fashioned which is roughly twice the length of the dorsal flap, the lateral incision being made at about the level of the midpoint of the bone The palmar flap is tongue shaped and the dorsal roughly semicircular. The two should fall together without tension The bone is sectioned at a level which allows these flaps to be approximated easily but without redundancy Preferably, the bone should be severed with a saw a little distal to the final amputation level, and the end should then be rounded off to a shape somewhat approximating the original cancellous tuft of the distal phalanx This is done with a rongeur and file The nerves should be grasped and pulled out by flexing the finger, they are cut as short as possible with a sharp knife or scissors and allowed to retract into soft fat When amputating near the palm, one should arrange to have the nerve stump as far proximal as possible as painful neuromata in the distal palm are horrid

In reamputation there is often an opportunity to shape flaps so that the palmar flap is long enough for a dorsal scar In doing this the nerve ends should be left fairly long so that the end has normal sensation and the neuromata will lie dorsally

The tendon ends which are free in the wound are grasped and drawn distally as far as possible, then cut off and allowed to retract If the tendons are adherent but the joints function normally, nothing special need be done except to remove enough tendon to reduce the bulk of the palmar side of the finger In the more complicated cases in which the tendon is adherent throughout its length and is definitely checkreining the hand, it may be necessary to open the palm through a transverse incision before the tendon difficulty can be eradicated The wound should be closed with interrupted end-on mattress sutures, with care taken to avoid dog-earing or puckering

Special Revision Technics

The usual causes of unsatisfactory results are inadequate padding, excessive scar with adhesions, excessive bone or tendon, and painful neuromata, or various combinations of these

phalangeal joints, the end of the amputated digit will stick out when the hand is flexed and is constantly being bumped The same applies to a lesser degree to a disarticulation through the distal interphalangeal joint Too much bone is always present if the prominences of the condyles are left Stiffening of the remaining joints is perhaps inevitable whenever one or more segments of the finger are removed Much of this stiffness is due to the patient's not being taught to use the finger with the others and can be avoided if postoperative training is carried out When joints are completely stiffened from trauma or disuse, amputation may be indicated to increase the usefulness of the other digits

During healing of a nerve that is severed, the axons grow out of the proximal stump into the surrounding tissue If this tissue is soft and the nerve is not traumatized constantly by every movement of the hand, no harm is done and normal sensation results If, on the other hand, the nerve endings grow into tissue which becomes scar and are constantly irritated by every movement and every pressure on the area, a pain phenomenon will develop In some patients the axons proliferate excessively and wind up on themselves to form a definite tumor-like mass or amputation neuroma It is much more difficult to overcome the pain phenomenon of unsuccessful primary amputations than to obtain good results at the primary procedure

Tendons which become adherent at the time of a primary amputation may interfere with subsequent use of the digit This is particularly true when the tendon has not been adequately cut back and becomes adherent to and moves the scar at the end of the finger Such a tendon occasionally will checkrein the motion of the other fingers as well It should be remembered that each segment of the finger has its own motor power, the profundus tendon acting on the distal phalanx, the sublimis tendon on the middle phalanx and the interossei on the proximal phalanx If more than one tendon is acting on the same phalanx, the muscle balance of the digit and of the rest of the hand may be somewhat upset.

The circulation of the hand is so good that, except in irritative and causalgic states, circulation of an individual digit seldom presents a problem This is not true when an injury to the circulation of the limb itself has occurred The hand will always survive the ligation of either artery in the forearm and sometimes of both, but if the brachial is lost above the elbow, gangrene of the hand or finger tips may occur Gangrene of the finger tips is also sometimes a result of partial injuries to the circulation of the arm

tively, the digital nerves should be sought in the volar flaps and properly excised One-half in of digital nerve can be sacrificed without causing permanent numbness of the end of the finger and usually with good sensation being present almost immediately After these steps, it is usually possible to fashion flaps which will adequately cover the end of the finger and which will to a great extent avoid scar in undesirable locations These flaps, of course, will not be those described under the ideal amputation,

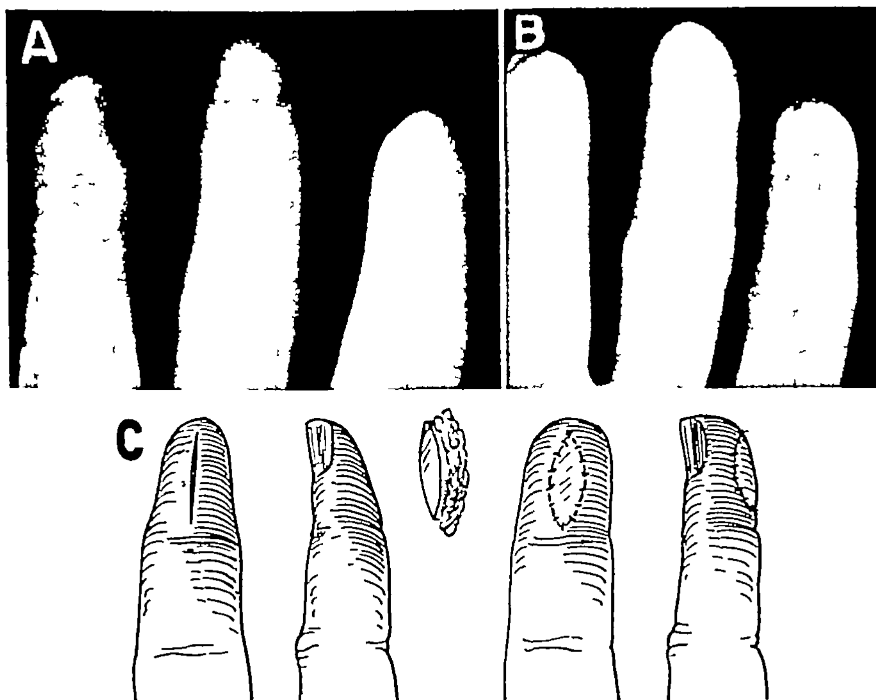


FIG 197 —Avulsion of finger pads caused when glove was caught in rollers of sheet metal bender *A*, result of original treatment by suture of wounds of index and long fingers and skin grafting on ring finger, bone ends are less than 1 mm from surface *B*, after revision operation, good padding was secured by excision of scar and cancellous tuft in index and long fingers (as in Fig 196), and in ring finger, same procedure plus use of free fat graft to provide padding *C*, method of increasing bulk or padding of end of finger by ear lobe graft of skin and subcutaneous fat The fat supplied is larger than the skin

but regardless of their shape no trouble need be anticipated if they are carefully fitted and fastened in place with fine interrupted sutures This procedure is not entirely without complications Occasionally, resecting the nerve results in gangrene of the skin flaps

3 *Excessive bone or tendon but adequate flaps*—When an improper primary amputation has been done, leaving the cartilage on the end of the condyles, as in a disarticulation, or suturing the tendons together over the end of the bone, a ganglion-like swelling or soreness over the end of

1 *Inadequate skin padding*—Closure of the original wound with a skin graft is in many cases apparently permanently satisfactory The finger eventually becomes rounded and adequately padded, the graft meanwhile shrinking and gaining normal sensation In others, the bone is always palpable and the finger is either pointed or squarish in appearance, without adequate padding (Figs 32, *B*, and 196) In these, a simple corrective procedure may be carried out A small ellipse of tissue is excised directly over the end and distal sides of the finger (Figs 196 and 197) The ellipse includes a part of the skin graft centrally and a little wedge of normal skin on each end of it The bony phalanx is then freed from soft tissues and enough of it rongeured away and given a rounded contour so that the soft tissues can again be closed over the bone Usually not more

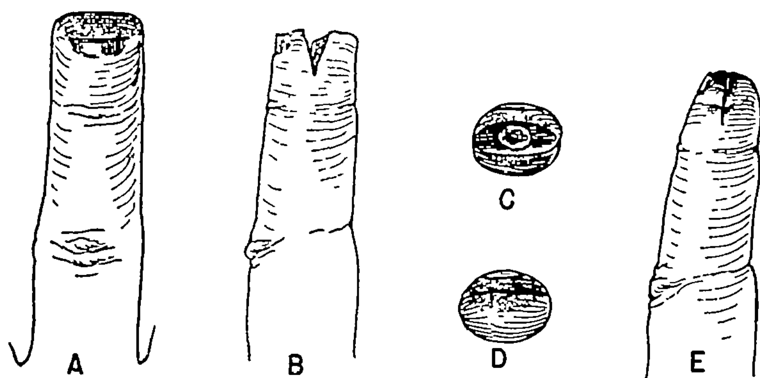


FIG 196—Revision of finger end when primary repair by skin graft is unsatisfactory *A*, appearance of healed finger with graft in place, *B*, line of incision, *C*, bone removed, *D* and *E*, closure

than ⅛–¼ in of bone need be removed for this procedure If no nerve phenomena are present and nerves are not encountered in the dissection, nothing need be done about them

2 *Excessive scar with adhesions to bone and pain*—This type of deformity usually occurs when parts of the original flaps slough or when infection occurs Treatment in these cases demands considerable ingenuity, since sacrifice of the entire scarred area may cause too much shortening of the finger whereas failure to sacrifice enough finger does little to improve usefulness An incision will often have to be made along the lines of the original scar Bone is then dissected out, shortened a little and contoured If possible, the scar incisions are elongated down the sides of the finger to allow good-sized flaps to be produced All the scar in the original area should then be excised, leaving only skin and fat If nerves are encountered in the scar or if nerve phenomena were present preopera-

the affected digit and that the process is not a typical causalgia, a good result can be obtained by eliminating the focus of irritation The finger does not need to be reopened through the former incision, although this is sometimes the practical approach if the bone end or flaps need revision A midlateral incision along the middle segment can be made and the digital nerves picked up without opening the end of the finger The nerves are transected about ¼–½ in from the end of the finger and the distal segments removed This procedure has been eminently successful in selected cases, especially if the condition has not been present for several years

The opinion of most experienced surgeons who treat these conditions is that in most irritative postamputation states a single technically correct reamputation is well worth while

Phantom Limb

All amputees above the age of six have some phantom limb sensation In children the body image or corporal schema is not developed until six or seven years Usually amputees have very severe sensations for a few weeks after amputation with gradual subsidence over a number of months Stump irritation due to painful neuromata, poorly fitting prostheses, and stump anoxia may cause persistence or recurrence of complaints The longer the phantom lasts the more difficult the cure becomes, because pain habit patterns develop

Usually if the patient can be persuaded to return to a useful and interesting occupation the complaints will gradually fade

BONE GRAFTING FOR NONUNION

Bone defects in the metacarpals or phalanges which may follow extensive trauma to the hand can be replaced satisfactorily by bone taken from elsewhere in the hand or body A defect commonly encountered is in the proximal phalanx of the thumb It is especially important that this digit be repaired because without a stable thumb there is very poor pinch and grasp in the rest of the hand

Preparation —Before any bone graft can be inserted, all the soft parts must be completely healed Pedicle flaps should be used if necessary to obtain adequate cover so that the bone grafting can be carried out through healthy tissue A careful assessment of the rest of the hand should be made and, if indicated, physical therapy should be instituted to over-

the stump frequently develops This requires reamputation The finger is opened through the scar of the previous amputation and bone is dissected out and cut back to the site of election After the bones are contoured, the flaps are manicured to fit, using a pair of sharp scissors Usually some approach to the ideal amputation type of flap can be secured (Fig 198)

4 *Sensitive finger end.*—When the bones and soft tissue are otherwise all right, this condition requires careful evaluation Frequently a causalgic

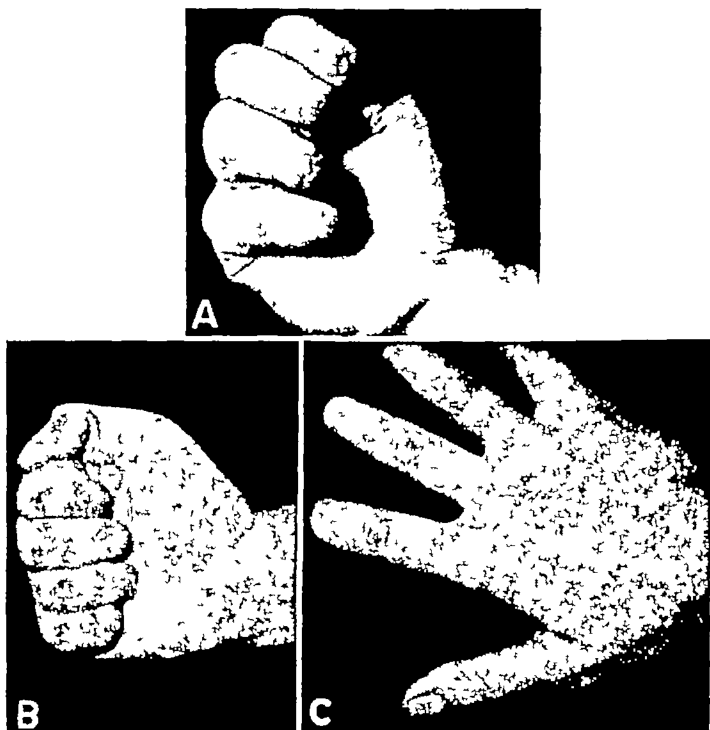


FIG 198 —*A*, appearance after amputation of index, long and ring fingers along line approximating distal interphalangeal joints, index and ring fingers still have clawlike nail spicules In revision, old scars were excised, bone exposed and the condylar expansions on bone ends flattened and rounded without sacrificing much length The nerves were pulled down and cut off, and skin flaps were reshaped, cutting away nail-bearing tissue *B* and *C*, result

state is present and surgery will simply aggravate the condition However, many cases are due to irritation from the nerve ends in the scar itself Procaine injections into a trigger point, if one is found, are helpful in diagnosis and sometimes aid in treatment Re-education of some patients in proper use of the hand results in a cure One important diagnostic aid is an x-ray which in irritative lesions will show demineralization of the affected digit

When it can be reasonably established that the irritative lesion is in

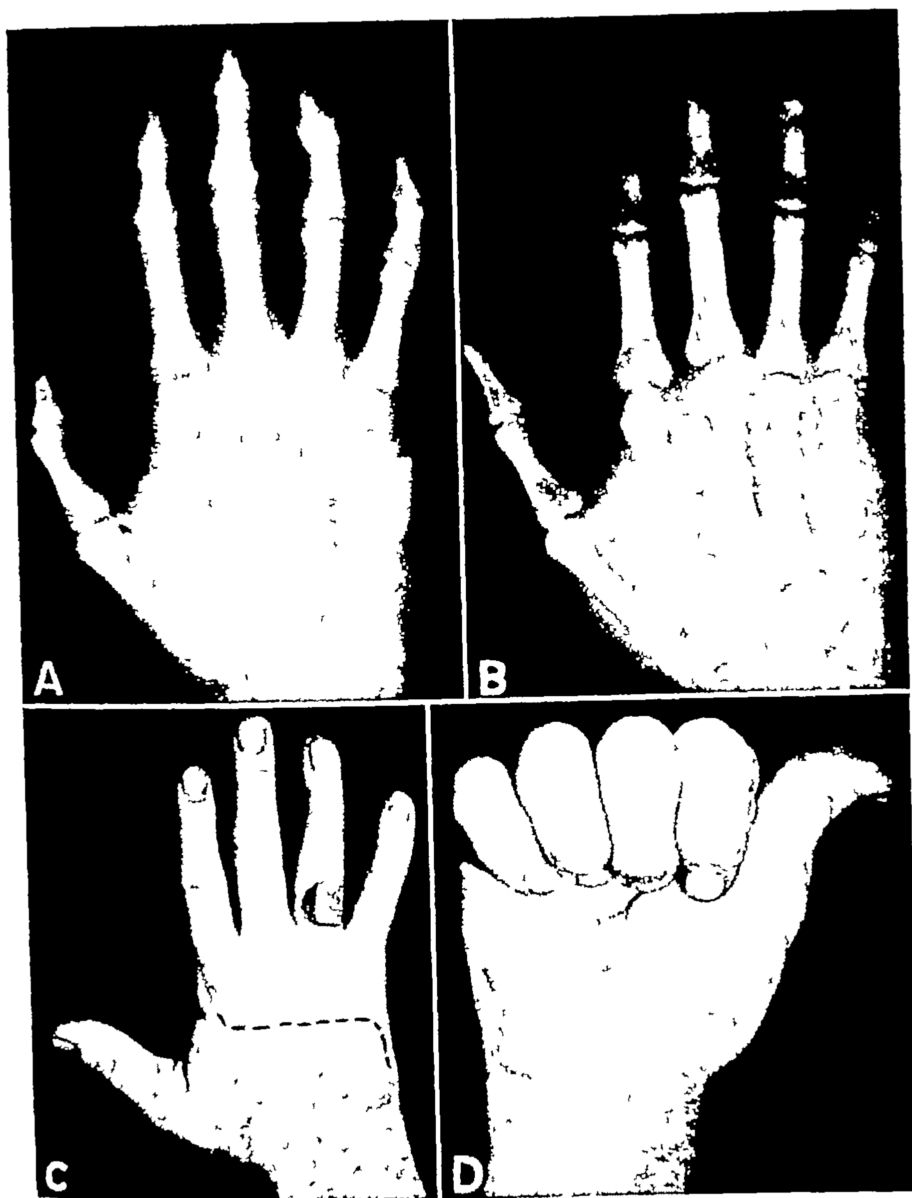


FIG 200—Repair of metacarpal fractures with stiff metacarpophalangeal joints (see Fig 143) *A*, bone grafts supplied using inlays and onlays and small plate on fifth finger So much stiffness was present that some bones were refractured during physical therapy, capsulectomy and additional fixation and grafting then done *B*, fractures healed, hardware removed *C* and *D*, end result, dotted line shows scar of operative procedure

come stiffness of the joints before grafting A suitable source for the graft may be a metacarpal or phalanx which will be sacrificed in the hand (Fig 199) This bone requires a longer period to unite but is sometimes technically more adaptable than soft, cancellous bone of the iliac wing

TECHNIC—All the precautions in asepsis which are ordinarily used in tendon grafts and other grafting operations must be observed, a bloodless field is desirable A power saw is almost an essential, in addition to miniature drills, screws, etc A long, midlateral incision is suitable in approaching phalanges For the metacarpals, the incision may be serpentine,

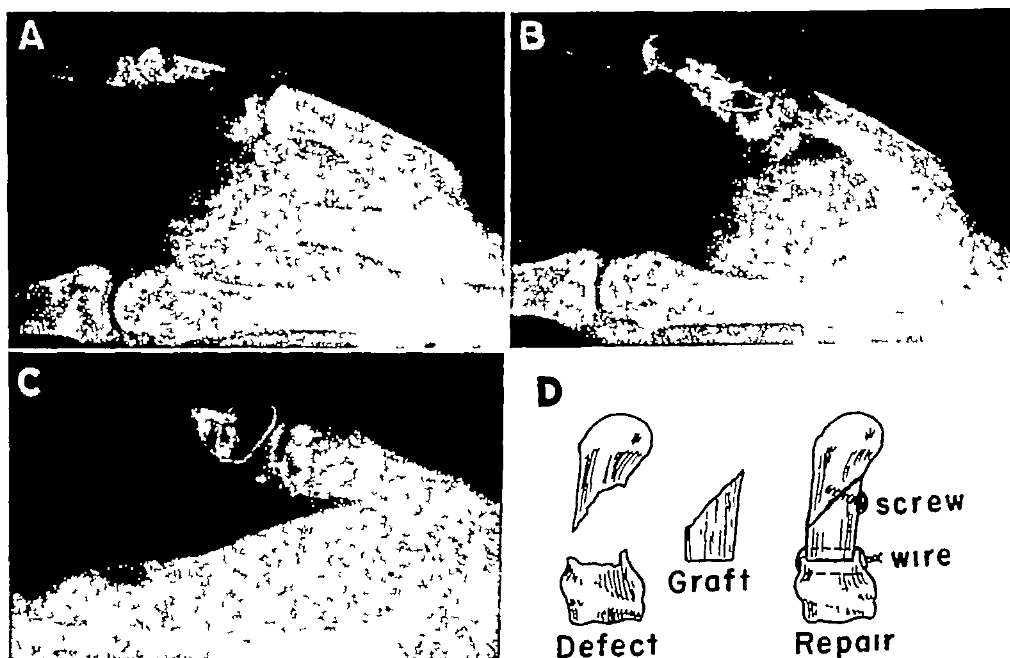


FIG 199—Bone graft of thumb *A*, defect in proximal phalanx of thumb Amputated index metacarpal was used for graft *B* and *C*, graft in place, bone healed solidly in four months *D*, technic of repair

transverse, zigzag or longitudinal After the bone ends are dissected out, a graft is cut to fit into the defect exactly, taking advantage of obliquity of the fragments where this is present The various parts must be fitted together with cabinet-maker's precision Usually some form of internal fixation is necessary to supplement the graft, and additional bone chips should always be packed around the fracture site The wound is closed in the usual manner and a plaster cast applied to hold the part immobilized in the position which relaxes any adverse muscle pull

When metacarpals or phalanges are bone-grafted it may be necessary to perform a capsulotomy on the adjacent joints and to immobilize the

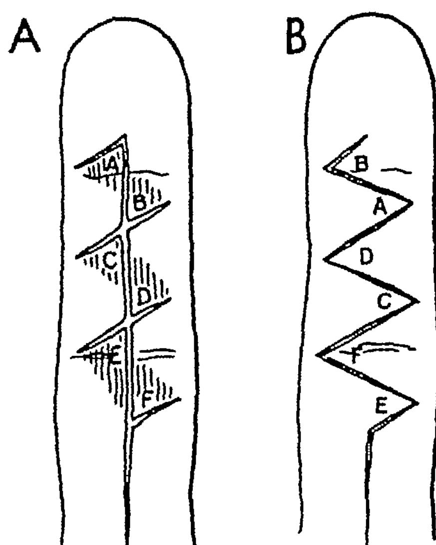


FIG 202—Z-plasty principle applied to bridle scar on finger. *A*, original incision is reopened and skin undermined about each Z. Equilateral triangles are formed by diagonal incisions *B*, tips of these triangles are transposed and wound closed in zigzag manner

fingers or thumb When enough tissue exists, adequate length can be obtained by a z-plasty procedure This maneuver obtains added length for the scar at the sacrifice of circumference of the finger. The scar is also changed from a single, unyielding line to an elastic zigzag line which works as a spring

The simplest technic to follow is to form a number of equilateral triangles on each side of a scar by placing alternate 60-degree angle incisions on each side The tips of opposing triangles are transposed, and the wound is closed in a zigzag manner (Figs 201 and 202).

TUBE PEDICLE—For the average surgeon the formation of a tubular pedicle presents a considerably more difficult problem than formation of a simple flap pedicle as described in Chapter 7 When the recipient area is long and thin rather than short and wide or when the angle at which the extremity meets the body is extremely awkward (when joints are ankylosed), a tube pedicle is almost a must Tubes are easier to handle because the circulation is better and they are more resistant to infection and trauma than the one-stage flap pedicles One of the objections to tube pedicles is the extra operative stage required Another is the additional planning necessary to make them fit the defect, since it sometimes happens that when the second stage, that of dissecting the hand, etc, is done, the tube may not be adequate to fit the hand On the other hand, tube pedicles may be easier on the patient when positioning is difficult.

parts with the joints flexed Otherwise the joints stiffen in extension during healing, and when they are later mobilized the grafted area will be refractured.

So many methods of bone grafting have been devised that an adequate description of all cannot be attempted. It is obvious that success in repairs of this type will depend on familiarity with a number of different methods A few suggestions are offered here and the reader is referred to the pertinent texts for more complete details.

It often happens that the soft tissues about an injured phalanx are also damaged. In this situation an allowance for some shortening should be made when the bone graft is used For malunion of a phalanx or a metacarpal, an osteotomy with an intramedullary peg plus bone chips and internal fixation has been satisfactory For nonunion of the metacarpals, slabs of cancellous bone laid alongside the fracture will give good union when accompanied by internal fixation of the fragments and attention to the metacarpophalangeal joints (Fig 200). Bunnell repaired defects here by diamond-shaped grafts taken from the olecranon and wedged into the medullary cavities of the metacarpals Littler has made pegs of iliac bone to replace metacarpals, and ribs have also been used.

In summary, the problems of bone grafting in the hand present in miniature all the problems of bone grafting of larger bones of the body The technical problems involved, however, are much greater due to the smallness of the parts and the relative lack of covering materials

Z-PLASTY AND TUBE PEDICLE

Z-PLASTY —In doing many of the simpler reconstructive procedures, the surgeon will be called on to revise scars which act as bridles on the

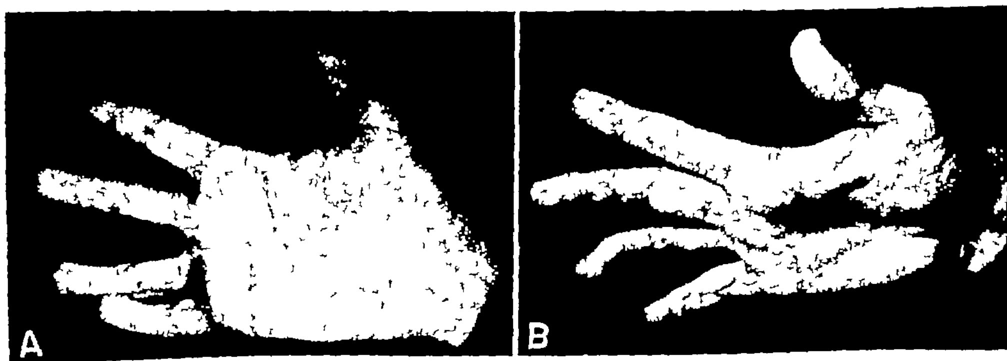


FIG 201 —*A*, heavy bridle scars with flexion contracture and loss of tendon function in three fingers, the result of pernicious longitudinal incision used in treatment of transverse laceration with severed tendons *B*, after Z-plasty and repair of severed tendons

remains and if a pincher can be formed, much benefit can be obtained, for the reconstructed hand is usually better than a prosthesis because it has both pinch and sensation The most practical procedure to accomplish this was presented by Graham, Brown and Cannon in 1949 Their operation was carried out in two stages At the first stage the metacarpal of the thumb is elongated by shifting and grafting the metacarpal of the

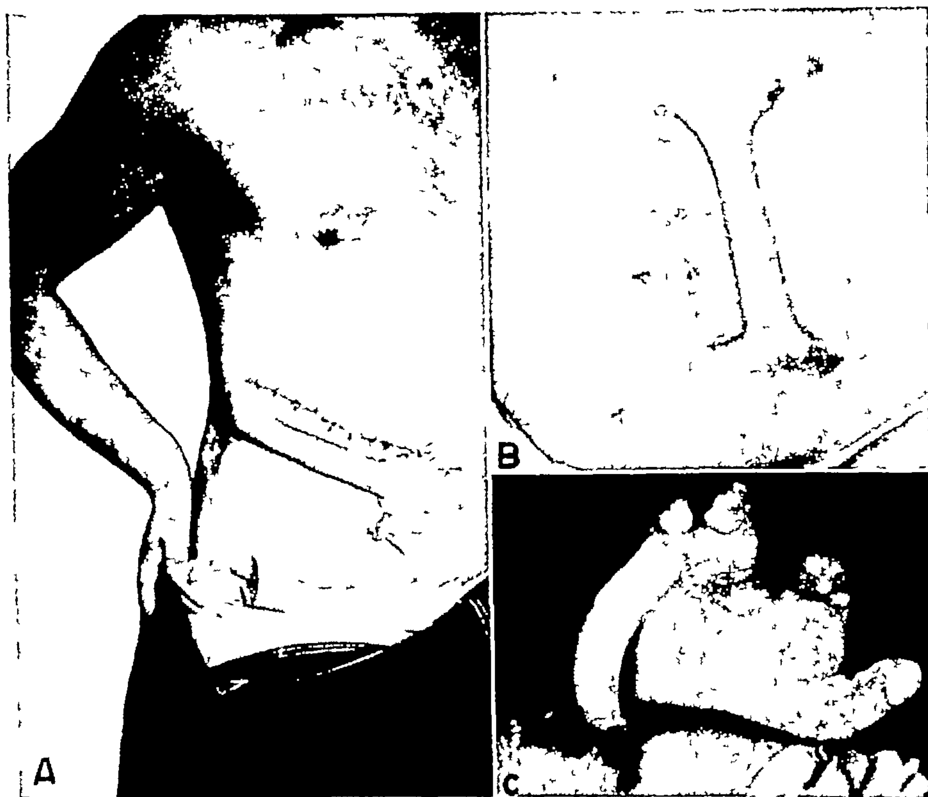


FIG 204 —*A*, tube on right lower abdomen ready for migration to hand Patient wears overalls to avoid pressure on tube *B*, vertical tube sometimes used when oblique type is not appropriate *C*, tube migrated to hand

index finger over onto it At a second stage a cleft is formed in the axis of the second metacarpal

This operation has been performed in one stage with an excellent outcome (Fig 205), using the following technic Incision is made through the skin of the palm and dorsum in the line between the second and third metacarpals A supplementary incision parallel to the dorsal incision raises a square-ended flap over the second metacarpal about the size of the operator's index finger The blood supply of this flap based proximally is carefully preserved After the flap is lifted, the stump of the thumb metacarpal can be approached from the dorsum The shaft and proximal

The technic of making a tube is illustrated in Figure 203 Parallel incisions are made through the skin and subcutaneous fascia and the skin is undermined between the incisions Bleeders are tied and enough subcutaneous fat is excised so that the edges of the skin bridge may be sewed together like a suitcase handle The defect of the donor site is closed by undermining and sliding the surrounding skin under the tube or by using

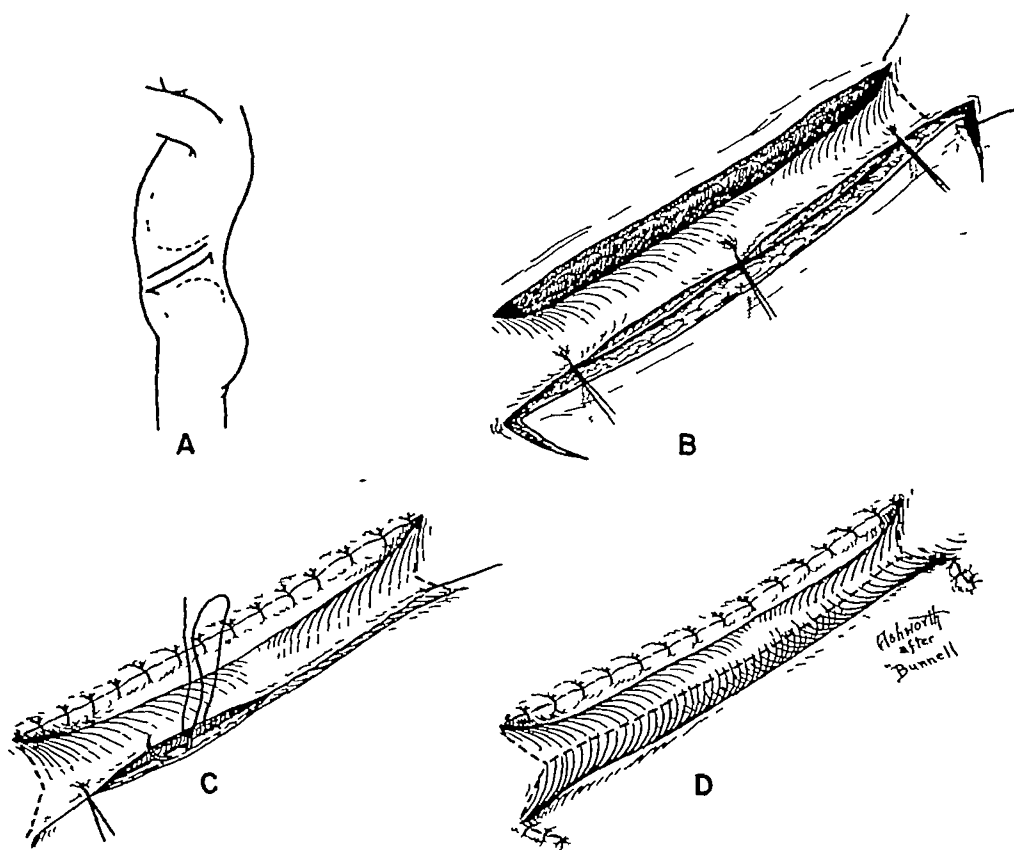


FIG 203 —Formation of tube (after Bunnell) *A*, line of incision for oblique tube, *B*, flap raised and tubed, *C*, abdominal wound is closed and tube then completed by suturing with subcuticular wire, *D*, completed operation

a free split thickness graft Three weeks should elapse before the tube is migrated to the hand On the average, an additional three weeks should elapse before the tube is severed from the abdomen (Fig 204)

FORMATION OF CLEFT IN PALM

Sometimes all the digits are severed, leaving the palm and wrist intact With this injury the rest of the hand is almost functionless If sensation

end of the index metacarpal are exposed and the metacarpal is transected close to its base The interosseous muscles on each side of this metacarpal are then split and dissection carried down onto the adductor pollicis This muscle is preserved along with its innervation from the ulnar. The skin and nerve supply are left intact on the lateral aspect of the index metacarpal, but the nerve to the second cleft is best cut short in the palm, ligating and dividing when necessary the superficial transverse palmar arch The first dorsal interosseous muscle is excised, if necessary, and the index metacarpal can then be set over onto the stump of the thumb metacarpal without difficulty The bone lengths should be adjusted so that the new thumb is about as long as the end of the third metacarpal The bone ends are joined by internal fixation and an intramedullary bone peg The skin flap on the dorsum is attached to the skin of the palm to form the base of the cleft and the sides of the cleft are closed with split thickness skin grafts This operation should enable the patient to pick up objects 1 in thick and to pinch tightly any smaller objects

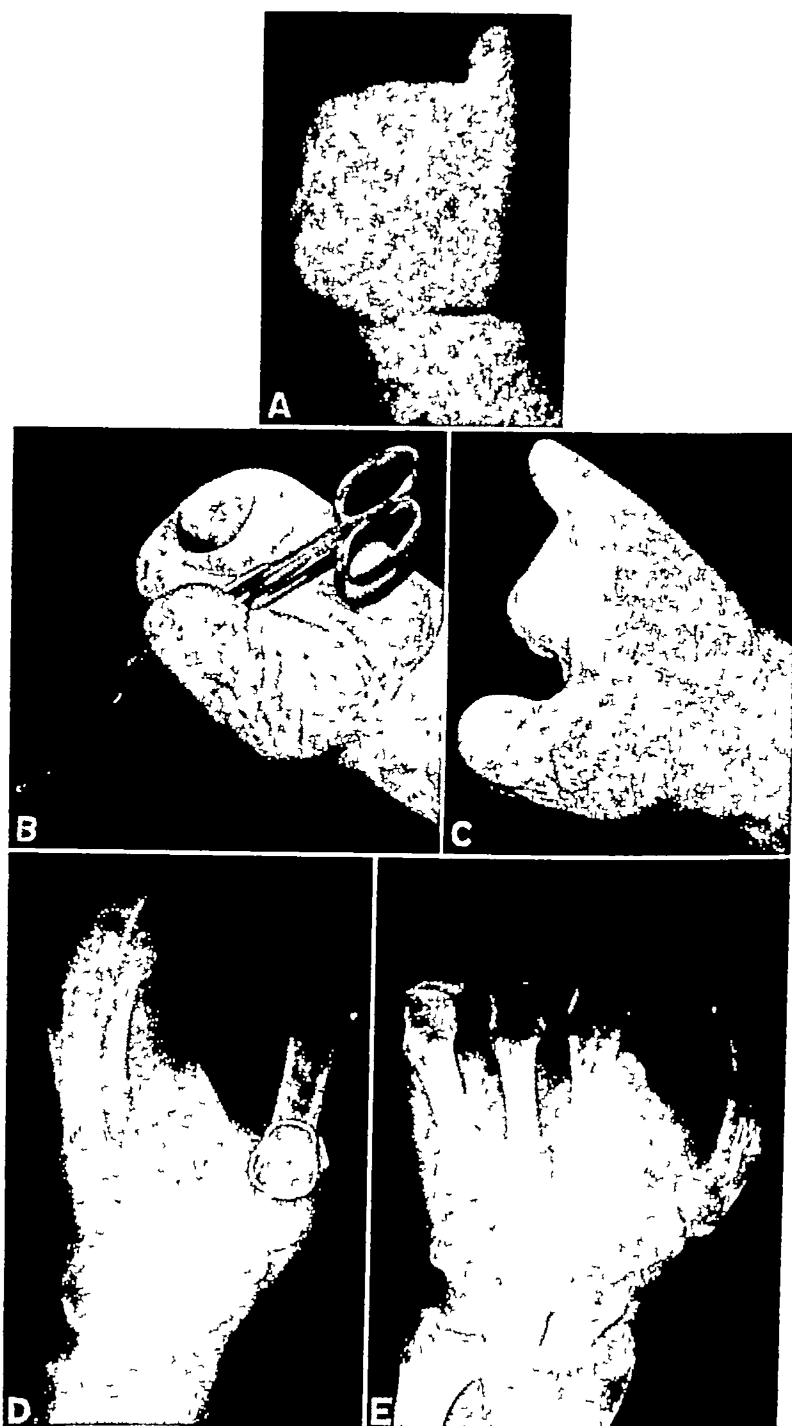


FIG 205 —Formation of cleft in digitless hand by shifting index metacarpal with attached skin to thumb position *A*, preoperative, *B* and *C*, function obtained postoperatively, *D* and *E*, postoperative x-rays

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